RESEARCH ARTICLE

REVISED Is entrepreneurship a key factor in the development of European countries? A proposal for an innovation readiness environment (IRE) index [version 2; peer review: 2 approved]

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Abstract

This study investigates the complex interplay among innovation, research and development (R&D), and entrepreneurship within the context of European nations. The focus of the study is also on the contributory role of tertiary educational institutions in nurturing entrepreneurial activities. To deepen the understanding of these multifaceted relationships and their subsequent impact on regional economies, the research introduces a novel metric termed the Innovation Readiness Environment (IRE) index. This index combines various indicators such as R&D expenditure, patenting rates, firm size, and educational levels, thereby providing a framework for evaluating firms' innovative capabilities and entrepreneurial success in a given region. Utilization of this index offers policymakers and stakeholders a nuanced understanding of the regional innovation ecosystem, facilitating the identification of strengths and deficiencies. This, in turn, enables the formulation of targeted policy interventions to enhance innovation and entrepreneurship. One relevant conclusion drawn from this study is the pivotal role of tertiary education in catalyzing entrepreneurial ventures. The findings posit that higher levels of entrepreneurial education significantly supplement an individual's likelihood of entrepreneurial success by imparting the requisite skills and knowledge indispensable in a competitive business

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milieu. By fostering an environment conducive to innovation, higher education institutions emerge as critical agents in cultivating entrepreneurial acumen and stimulating economic expansion. The study further incorporates a spatial analytical framework to elucidate the regional specificities of innovation at the pan-European scale.

Keywords
Research and Development, Innovation, Entrepreneurship, Innovation Readiness Environment Index, Tertiary Education, Patent Application, Spatial Analysis

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REVISED **Amendments from Version 1**

In response to the feedback received from the reviewers, we extended the literature review to provide a more thorough comparative analysis with existing metrics such as the Global Innovation Index (GII), European Innovation Scoreboard (EIS), Regional Innovation Scoreboard (RIS), and the Global Entrepreneurship Index (GEI). Additionally, we provided a detailed explanation of the criteria for selecting indicators, clarifying the rationale behind their inclusion. We also linked the IRE index more robustly to policymaking and economic growth, highlighting its implications and potential benefits for stakeholders and policymakers.

We also enhanced the methodology section to include specific information on indicator selection, delineating any limitations or potential biases associated with these sources. Finally, we integrated these insights into the section on limitations and future research directions. We acknowledged the current constraints of the IRE index and suggested avenues for future research to address these gaps, including the incorporation of aspects of the Regional Innovation Indicators and the usage of GERD for a more nuanced perspective. This comprehensive approach ensures that our study is more impactful and relevant to the academic community and policymakers alike.

Any further responses from the reviewers can be found at the end of the article

1. Introduction

In the context of the 2030 Agenda for Sustainable Development (SDG) (https://sdgs.un.org/2030agenda), entrepreneurship plays a pivotal role in enhancing society's quality of life, including for disadvantaged groups, as it contributes to building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. Entrepreneurship is closely linked to SDGs 4 and 8, reviewed in 2019. SDG target 4.4 aims to significantly increase the number of youth and adults with relevant skills, including technical and vocational skills, for employment, decent jobs, and entrepreneurship. Simultaneously, SDG target 8.3 supports development-oriented policies that promote productive activities, decent job creation, entrepreneurship, creativity, and innovation while encouraging the formalization and growth of micro-, small-, and medium-sized enterprises (MSMEs) as critical agents for and beneficiaries of inclusive development through access to financial services.

Entrepreneurs with a strong commitment to sustainable development contribute to achieving almost all SDGs as they create businesses that support employment, alleviate poverty, and enable decent work and economic growth. Furthermore, entrepreneurship benefits efforts to reduce hunger, promote good health and wellbeing, achieve affordable and clean energy, and strengthen industries. Thus, entrepreneurship can be the driving force behind transforming our world and overcoming diverse global challenges (Apostolopoulos, 2018).

Recognizing the importance of entrepreneurs and entrepreneurship, the European Commission has launched the "Entrepreneurship 2020 Action Plan" which aims to unleash Europe's entrepreneurial potential, eliminate existing obstacles, and modernize the culture of entrepreneurship in Europe. These goals can be achievable through fostering an entrepreneurial mindset through entrepreneurship education in higher education institutions. Universities' teaching activities shape students' entrepreneurial orientations and competencies. Recent research suggests that university entrepreneurship programs may not increase the rate of entrepreneurship, but they do help students to better identify their entrepreneurial potential and improve the performance of their startups, leading to higher success rates, improved employability, and better management skills. It is crucial to consider regional differences and analyze regional innovation indicators to foster entrepreneurial spirit, create prosperity and wellbeing, and facilitate European system growth. This necessitates understanding each region's trajectory through tools like the Smart Specialization Strategy (S3) and Smart Specialization Strategies for Sustainable and Inclusive Growth (S4). To better comprehend regional situations, we propose an "ad hoc" index reflecting the entrepreneurial tendencies of specific regional territories.

The remainder of the paper is organized as follows: Following the introduction in Paragraph 1, Paragraph 2 elucidates the theoretical underpinnings of the IRE index. Paragraph 3 delineates the methodology for selecting the appropriate variables and illustrates the steps in creating the IRE index, whereas Paragraph 4 discusses the results. Finally, Paragraph 5 provides the concluding remarks.

2. Theoretical background

The Entrepreneurship 2020 Action Plan is a comprehensive strategy for catalyzing and disseminating the culture of entrepreneurship in Europe through transforming entrepreneurial universities and nurturing entrepreneurial spirit. The plan is structured around three key pillars: entrepreneurial education and training, fostering an environment in which entrepreneurs can flourish and grow, developing role models, and engaging specific groups with untapped entrepreneurial potential or those not reached by traditional business support methods.

The first pillar emphasizes the importance of expanding and enhancing entrepreneurial education and training, which is considered one of Europe's most significant investments. The acquisition and implementation of entrepreneurship skills have also been highlighted within the framework of EU co-operation in education (Jenner, 2012). Overall, investments in entrepreneurial education are efficient tools for raising public awareness of entrepreneurs and supporting underrepresented groups among entrepreneurs. Only if a large number of Europeans perceive an entrepreneurial career as a rewarding and attractive option will entrepreneurial activity thrive in Europe in the long term.

However, Benneworth and Osborne (2015) argued that entrepreneurship education has not yet reached its full potential, partly due to poor integration with other university knowledge activities. The authors suggest that future research on university entrepreneurship education should focus on how entrepreneurial activities align with universities' core knowledge, providing

a more coherent understanding of universities' contributions to fostering entrepreneurial attitudes.

The global configuration of knowledge and technology is one of the most critical factors influencing the pursuit of internationalization and the rise of the global economy (Posselt *et al.,* 2019). The rapid evolution of technology and market demands necessitates the development of an entrepreneurial spirit, digital literacy, and innovative learning and teaching methods. In this context, entrepreneurial universities must adapt by cultivating leadership, navigating complexity, adopting a lifelong learning approach, and transforming failure into success (Gibb *et al.,* 2013).

These four essential features of entrepreneurs and entrepreneurial universities play a crucial role in promoting entrepreneurship in Europe. By focusing on these core values and principles, the Entrepreneurship 2020 Action Plan aims to revolutionize the landscape of entrepreneurship and support Europe's long-term economic growth and development.

The current literature has several well-established indexes and frameworks for assessing innovation and entrepreneurship at the national and regional levels. To provide a comprehensive overview and contextualization of the IRE Index, we have included a brief overview of several indices, in particular, the Global Innovation Index (GII), European Innovation Scoreboard (EIS), Regional Innovation Scoreboard (RIS), Global Entrepreneurship Index (GEI), OECD Science, Technology and Industry Scoreboard.

The GII provides detailed metrics that capture the state of innovation performance in countries around the world (Global Innovation Index, 2023). It includes indicators such as institutions, human capital and research, infrastructure, market sophistication, business sophistication, knowledge and technology outputs, and creative outputs. By analyzing 132 economies, the GII is seen as an "action tool" for innovation policy, as it enables policymakers to identify strengths, address weaknesses and implement effective strategies to improve their countries' innovation performance.

The EIS provides a comparative analysis of the innovation performance of EU Member States, other European countries, and regional neighbours (European Commission, 2023). It classifies indicators into four groups: framework conditions, including human resources, attractive research systems and digitalization. Second, investments cover finance and support, business investment, and information technologies. Third, innovation activities, including innovators, linkages, and intellectual assets. Lastly, there are impacts, such as employment effects, turnover effects, and environmental sustainability. Based on the scores, countries are classified into four performance groups: Innovation Leaders, Strong Innovators, Moderate Innovators, and Emerging Innovators.

While the EIS assesses innovation performance using a set of national-level indicators, the RIS (European Commission, 2021) provides a detailed regional perspective using indicators adapted to capture regional dynamics and specificities. The RIS uses a subset of the EIS indicators adapted to regional specificities. By providing insights at the regional level, the RIS allows the comparison of different regions within countries, highlighting regional disparities and identifying specific areas for policy intervention.

The GEI comprehensively measures a country's entrepreneurial ecosystem by assessing individual and institutional factors (Szerb *et al.*, 2020). The data is collected at the individual level, such as the attitudes, abilities, and aspirations of the local population, reflecting their readiness and potential to become entrepreneurs. These metrics are then weighted against the broader social and economic infrastructure, which includes elements such as broadband access, transport links to external markets, the regulatory environment, and the availability of financial resources. This approach enables GEI to capture the population's inherent qualities and the external conditions that facilitate or hinder entrepreneurship activity.

OECD Science, Technology and Industry Scoreboard includes indicators such as R&D expenditure, innovation outputs such as patent applications and high-tech exports, and human capital measures such as tertiary education attainment levels and the number of researchers (OECD, 2023). It also tracks metrics on the digital economy, data on collaboration and networks, government policies and support mechanisms, and the wider economic impact of innovation, including productivity growth and job creation. This in-depth analysis helps policymakers, researchers, and business leaders make informed decisions to improve national and regional innovation ecosystems and drive sustainable economic development.

In the following subsections, we present an exploration of the key indicators that were scrutinized during the development of the IRE index. The aim is to inform you of their respective significance and their impact on a given region's innovation readiness.

2.1 The role of tertiary education on the population aged 25–34

Education is essential both at the individual level, as it is key to navigating the world, and at the national level, as it contributes to a country's economic and societal development. Recent research has emphasized the critical role of education as a supply-side factor in the context of entrepreneurship and innovation, particularly in tertiary education, also known as post-secondary education or advanced studies (Crecente-Romero *et al.,* 2018; van Praag & van Stel, 2013).

Tertiary education is shaped by government policies and is seen as an effective instrument for advancing human and national development. According to Peña-Vinces & Audretsch (2021), its primary aim is to enhance employees' educational and professional levels across various specializations. This, in turn, increases the number of highly skilled workers, which boosts company performance and, consequently, the country's economy.

Furthermore, research conducted by Millán *et al.* (2014) revealed that education levels are positively related to

entrepreneurial success, as highly educated individuals contribute to a company's prosperity by running their own businesses or providing their skills and expertise. Similarly, Jiménez *et al.* (2015) argued that the impact of tertiary education is twofold. On the one hand, it increases formal entrepreneurship due to higher self-confidence and lower perceived risk, while on the other hand, it reduces informal business activity. The negative relationship stems from an increased awareness of and sensitivity to the potential negative consequences of certain activities. In parallel, Barreneche García (2014) found that the more individuals are involved in tertiary education, the greater the positive entrepreneurial dynamism.

Taking together the evidence from the literature, the indicator of tertiary education is seen as a vital factor for fostering entrepreneurial activities. As a result, we considered it a general measure of the supply of advanced skills across various industries and sectors.

2.2 The role of lifelong learning in innovation activities

The European Commission defines lifelong learning as "all learning activity undertaken throughout life, with the aim of improving knowledge, skills, and competencies within a personal, civic, social, and/or employment-related perspective." In other words, it refers to all formal, non-formal, and informal learning. Furthermore, Jarvis (2007) expanded the concept of learning by specifying two types-- vocational and non-vocational- and emphasized that learning covers any opportunity to acquire new knowledge, skills, attitudes, values, emotions, beliefs, and senses through social institutions or any process.

The concept of lifelong learning can be viewed from three perspectives: individual lifelong learning, learning organizations, and learning societies (Tight, 1998). These dimensions underscore the value of learning for development at the individual, company, and national levels. For example, Coelli & Tabasso (2019) study found that engaging in education improves labour market performance and, specifically, employee outcomes such as working hours or wage rates. Moreover, lifelong learning benefits society by potentially increasing company output and tax revenues. In the context of learning organizations, McKelvey (1998) emphasized that the connection between learning and innovation enables companies to overcome challenges through their ability to learn and adapt.

For further analysis, the lifelong learning indicator is essential, as it strongly correlates with innovation activities (such as the development of artificial intelligence and nanotechnologies). Overall, lifelong learning, including formal and informal education, enhances knowledge, skills, and competencies.

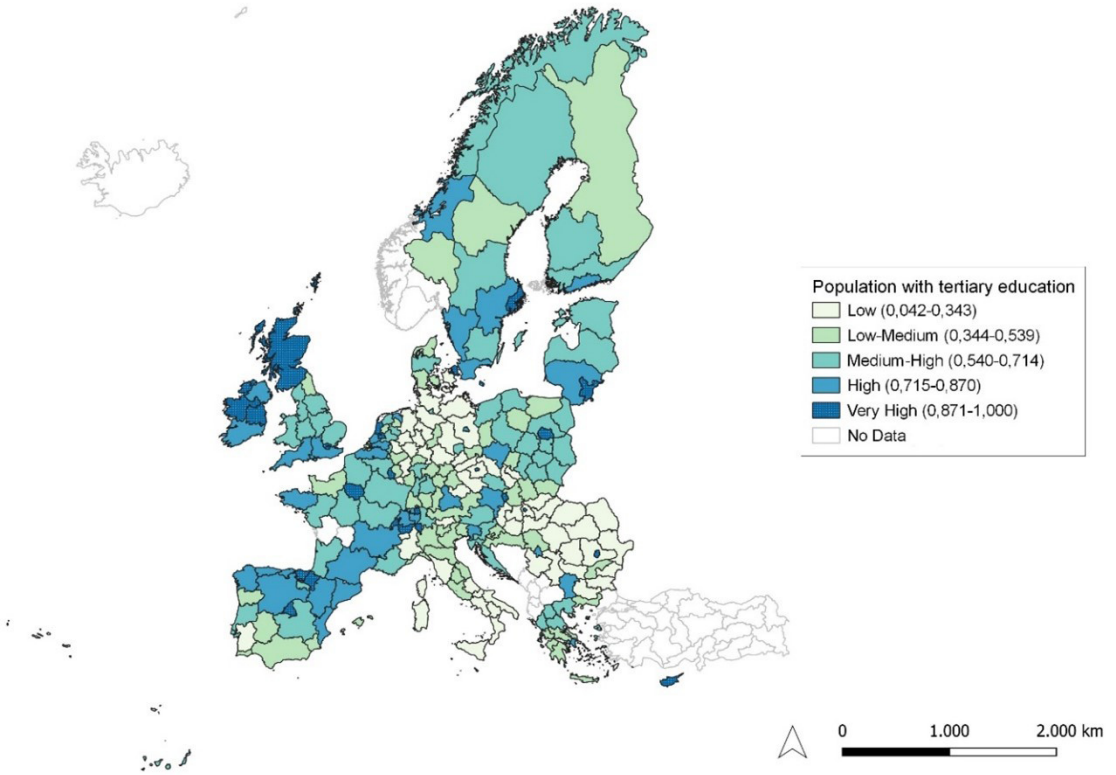

Figure 1. Percentage of the population aged 25–34 having completed tertiary education. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

Table 1. The selected indicators and data sources.

Indicator	Numerator	Denominator	Data sources	Data availability
Percentage population aged 25–34 having completed tertiary education	Number of persons in age class with some form of post-secondary education	The reference population is all age classes between 25- and 34-years inclusive	Eurostat, regional statistics, Regional innovation scoreboard 2021	NUTS 2: 2012 – 2019
Percentage population aged 25–64 participating in lifelong learning	Number of persons in private households aged between 25 and 64 years who have participated in the four weeks preceding the interview, in any education or training, whether or not relevant to the respondent's current or possible future job	Total population aged between 25 and 64 years	Eurostat, regional statistics, Regional innovation scoreboard 2021	NUTS 2: 2012 – 2019
R&D expenditure in the business sector	All R&D expenditures in the government sector (GOVERD) and the higher education sector (HERD)	Regional Gross Domestic Product	Eurostat, regional statistics, Regional innovation scoreboard 2021	NUTS 2: 2011 – 2018
Innovative SMEs collaborating with others as percentage of SMEs	Number of SMEs with innovation co-operation activities. Firms with co-operation activities are those that have had any co-operation agreements on innovation activities with other enterprises or institutions.	Total number of SMEs	Community Innovation Survey: Eurostat and National Statistical Offices	NUTS 1 and 2 for different countries for CIS 2012, CIS 2014, CIS 2016, CIS 2018
PCT patent applications per billion regional GDP	Number of patents applied for at the European Patent Office (EPO), by year of filing.	Gross Domestic Product in Purchasing Power Standard	Numerator: OECD, REGPAT. Denominator: Eurostat	NUTS 2: two-year averages for 2012 - 2019
Sales of new-to-market and new-to-firm innovations in SMEs as percentage of turnover	Sum of total turnover of new or significantly improved products for SMEs	Total turnover for SMEs	Community Innovation Survey: Eurostat and National Statistical Offices	NUTS 1 and 2 for different countries for CIS 2012, CIS 2014, CIS 2016, CIS 2018

Sources: authors' elaborations based on data as listed in the table.

2.3 The role of R&D expenditure in the entrepreneurial ecosystem

Research and Development (R&D) encompasses innovative and structured actions to obtain new knowledge and enhance existing knowledge (Eurostat). In recent years, extensive literature has focused on the relationship between R&D expenditures and firm performance. This interest stems from Schumpeter's theory, which posits that companies attempt to foster innovation in order to bolster their competitive advantages, potentially leading to higher profitability, productivity, and even market monopolies (Capasso *et al.,* 2015). Today, interest in innovation continues to grow due to the rapid development of technologies and the availability of highly skilled labour. Another contributing factor is the opportunity to expand activities in foreign markets, causing R&D to become increasingly supply-driven as companies adopt a more global orientation (Siedschlag *et al.,* 2013).

However, R&D investments can be challenging, as the positive impact of R&D on a company's innovative performance may increase up to a certain point, after which further R&D spending may lead to diminishing performance (Berchicci, 2013). Nonetheless, most scholars emphasize the beneficial role of R&D, particularly for a firm's productivity growth (Cin *et al.,* 2017; Kancs & Siliverstovs, 2016; Wakelin, 2001), marketing performance (Sharma *et al.,* 2016), employment rates (Di Cintio *et al.,* 2017), and overall future performance (Ruiqi *et al.,* 2017). Consequently, company growth tends to improve the economic situation within a country. For instance, research found that R&D expenditures and educational factors are most efficient in increasing GDP per capita. However, the analysis also revealed that the impact of R&D varies among regions; it is significant only in the most developed regions of Europe, while education is relevant in all cases (Sterlacchini, 2008).

R&D expenditures are considered one of the most influential drivers of economic growth at both the company and national levels. Additionally, they are crucial for transitioning to a knowledge-based economy, as they advance production technologies, leading to economic growth. For this reason, we included this measure in our analysis, as it may provide a

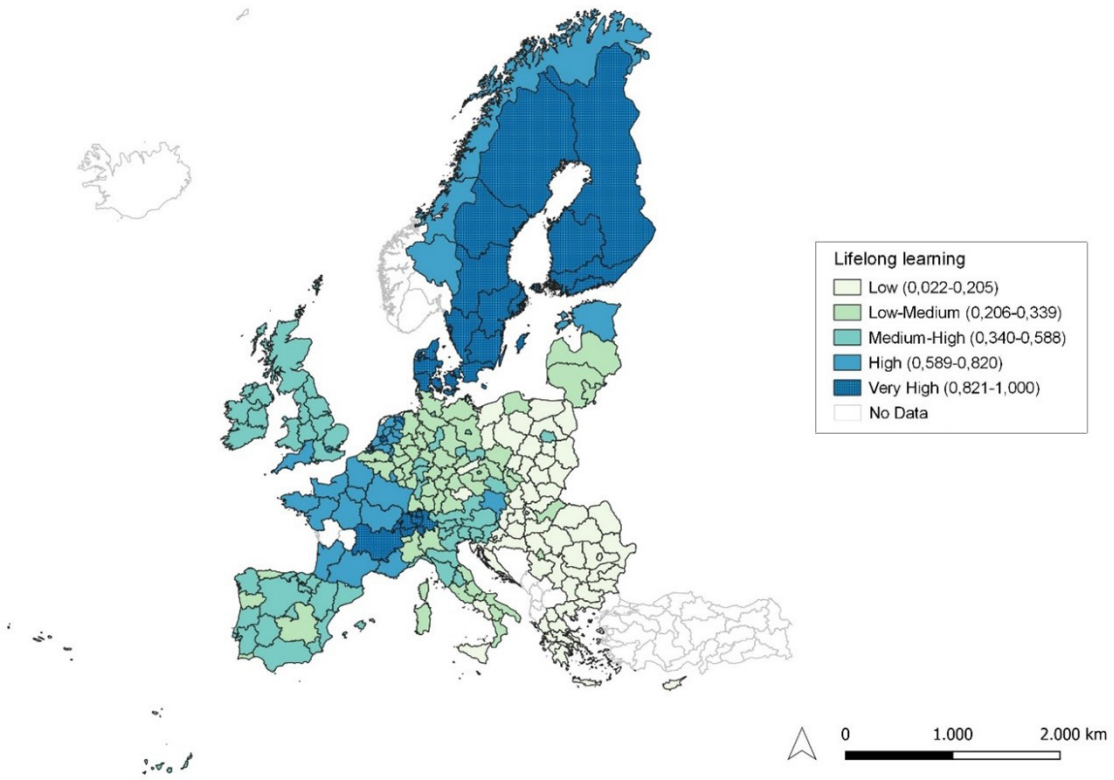

Figure 2. Lifelong learning. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

more comprehensive view of the degree of innovativeness in European regions.

2.4 The role of innovative SMEs and their collaboration activities

Due to their size, small and medium enterprises (SMEs) are often more vulnerable to challenges in the business environment. Nevertheless, most academic evidence suggests that innovations can effectively enhance SMEs' performance. For example, Hall *et al.* (2009) investigated the relationship between innovations and firm productivity, discovering that R&D intensity and investments in equipment are positively related to performance outcomes. Moreover, Laforet (2013) found that SMEs with an innovation orientation are more successful in the market, as they can quickly respond to market demand with better quality products or services.

In addition to improving domestic performance, innovations can help SMEs expand their international activities. By implementing organizational and product innovations, companies can bolster their marketing innovations. Integrating these innovations with technological advancements enables SMEs to increase exports (Bodlaj *et al.,* 2020). Meanwhile, the analysis of Saridakis *et al.* (2019) observed that innovative SMEs are more likely to extend their activities overseas than their non-innovative counterparts. Furthermore, the impact of innovation on internationalization varies among SMEs depending on the nature of the innovation and the degree of novelty. Similarly, Rosenbusch *et al.* (2011) identified additional factors affecting innovation outcomes, such as the company's age and the cultural context.

Measuring innovative activities in SMEs advances research by revealing current market trends in terms of SMEs' adoption of open innovations within the European context. This indicator specifically focuses on SMEs implementing, promoting, and collaborating with educational organizations on innovative initiatives. More precisely, it measures the flow of knowledge between public research institutions and firms and between firms themselves.

2.5 PCT patent applications

The context of innovation is closely related to patent applications, as they enable companies to distinguish their inventions overseas and protect intellectual property rights (Ervits & Zmuda, 2018). Patent applications are commonly used as indicators of innovation output within academic literature. For instance, Bronzini & Piselli (2016) assessed firm innovation through patenting activity, finding that implementing regional subsidy R&D programs led to an increase in patent applications, which positively impacted a company's innovation activities. Meanwhile, their analysis revealed company size as a distinguishing factor, with SMEs tending to exhibit higher intensity and likelihood of patenting than large firms. In

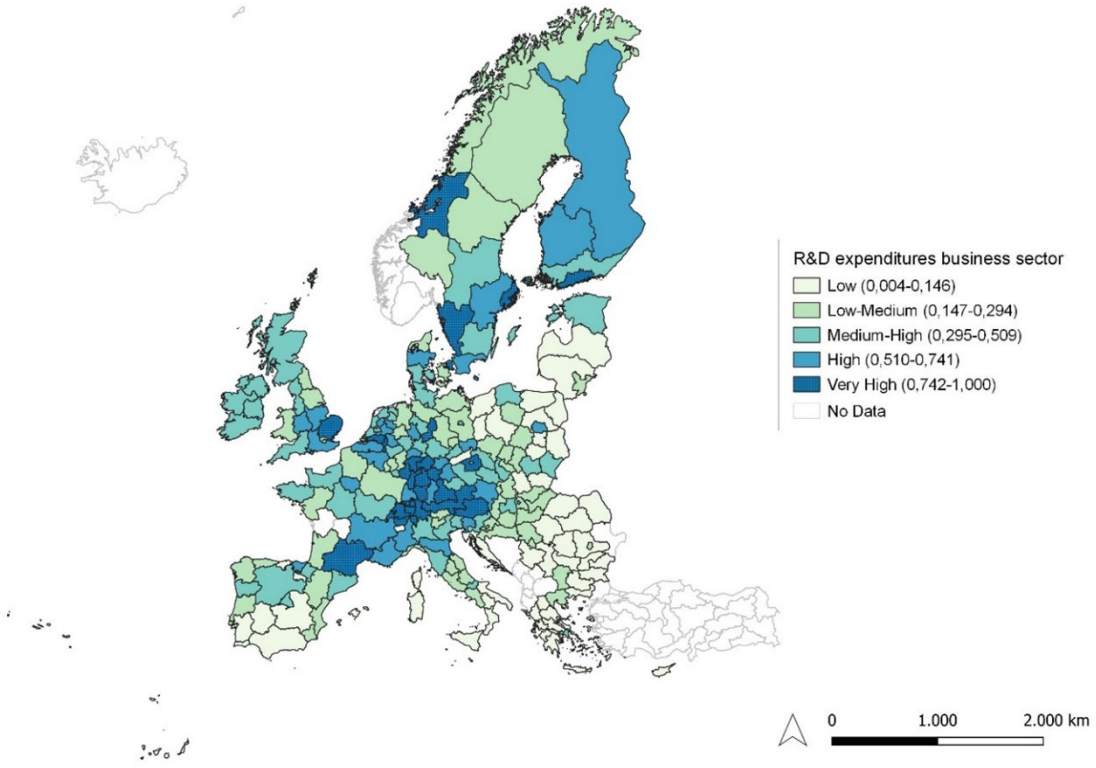

Figure 3. R&D expenditure in the business sector. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

contrast, Athreye *et al.* (2021) argued that larger companies can produce more patentable innovations due to existing cost barriers. Similarly, the study of Arundel & Kabla (1998) established a link between firm size and patent propensity rates. Furthermore, patents were identified as tools for protecting products and processes from being copied by competitors in the market.

Another line of research has focused on exploring the role of patent applications at the regional or national level. From a regional perspective, Lin *et al.* (2022) developed a two-stage model of the value-creation process within a regional innovation system, considering various patent statuses. Their findings revealed that invention patents play a crucial role in the overall performance of regional innovation development, as increasing patent applications lead to higher regional innovation scores. In another study, Whitacre *et al.* (2019) examined methods for measuring business innovation, creating an innovation index that allowed for the analysis of the relationship between innovation and firm- and regional-level outcomes. As a result, the research determined a positive impact of innovations on both firm and regional outcomes, with companies benefiting from increased employee wages and market share. Simultaneously, at the regional level, innovations influenced household income, the percentage of employees in the creative class, and poverty levels. In a broader view, Ervits & Zmuda (2018) conducted a cross-country analysis focusing on the impact of corruption and the business climate on patenting activity. Notably, countries with higher scores in institutional environments tend to exhibit greater incentives for patent applications. Consequently, companies, particularly SMEs, that lack ownership advantages and other resources may benefit from such environments.

Patent applications can be seen as an indicator of a firm's ability to develop new products, leading to increased competitive advantages. As such, it is a critical measure of a company's innovative activities. More specifically, we considered this indicator the number of patent applications per year within European regions.

2.6 The role of sales of new-to-market and new-to-firm innovations

Current EU innovation policies are primarily research-oriented, aiming to achieve an R&D investment rate of 3.1% of GDP. However, SMEs' innovative activities depend on internal factors, including both R&D and non-R&D factors and external factors, such as partnerships with companies and research centers. The recent study of Hervas-Oliver *et al.* (2023) argued that the success of innovation policies depends on a region's potential, as high investments in R&D may not necessarily lead to better performance for SMEs in less

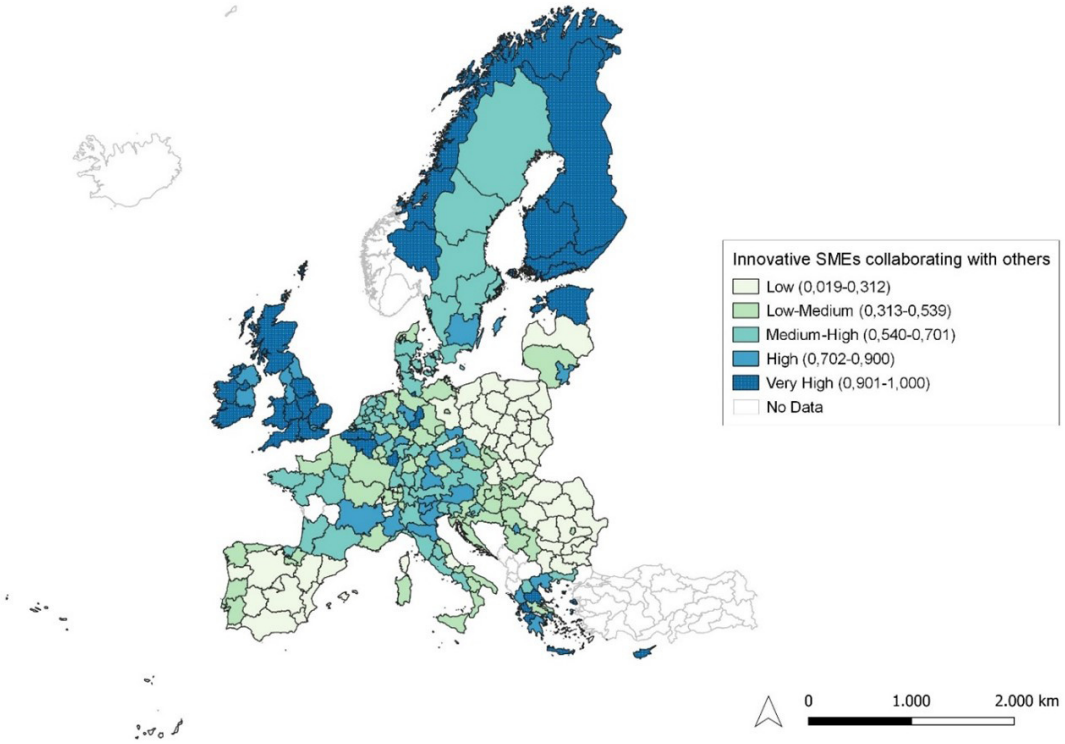

Figure 4. Innovative SMEs collaborating with others as a percentage of SMEs. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

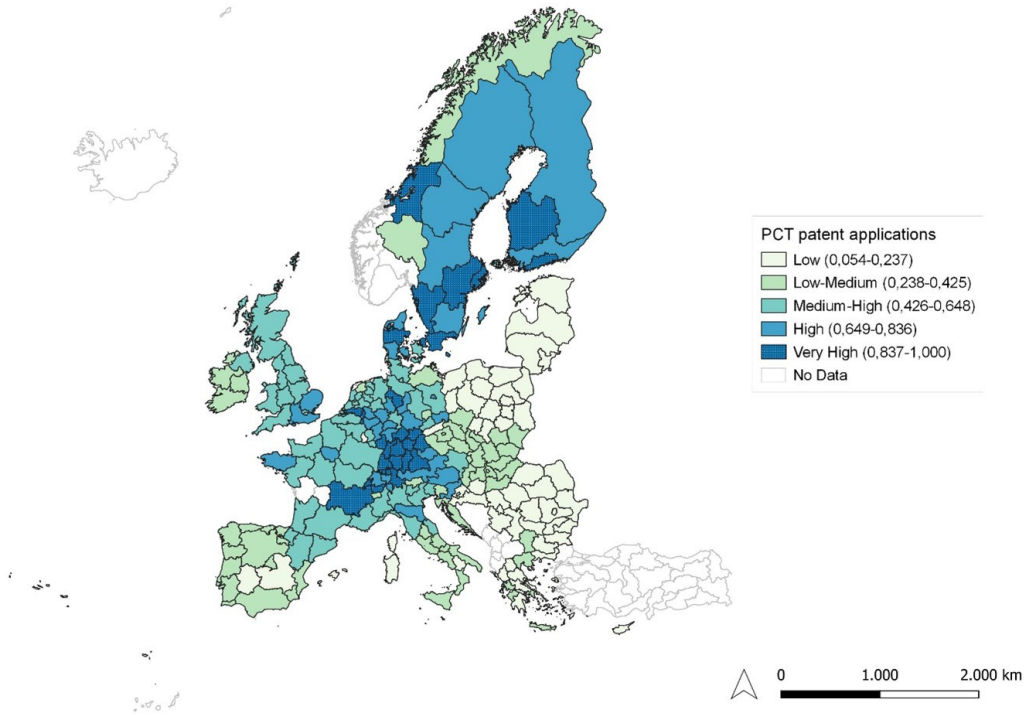

Figure 5. PCT patent applications. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

developed regions. Consequently, the degree of SME' innovation varies among European regions. The findings suggest that SMEs in more developed locations benefit mainly from all factors, while companies in less innovative regions heavily rely on external support.

Due to existing constraints, such as scarcity of resources and capabilities for developing R&D activities (Hausman, 2005), weak network embeddedness (Srinivasan *et al.,* 2002), or a lack of highly skilled employees (Romano, 1990), SMEs are compelled to seek solutions to overcome these barriers. One possible approach is through collaboration. Golonka (2015) posits that a more market-focused co-operation strategy could enhance SMEs' innovativeness. Thus, to minimize regional disparities, more collaborative and location-sensitive policies are required to advance SMEs' innovation activities.

For further investigation, we introduced an indicator that measures the turnover of new or significantly improved products. This includes new products for the firm and new products for the market. This approach enables the capturing of the creation of cutting-edge technologies (new-to-market products) and the diffusion of these technologies (new-to-firm products).

3. Methods

To achieve the objectives of the research, the methodology for the development of the IRE index was executed through a multi-step procedure. After the above-mentioned review of extant literature to identify the critical variables that influence innovation, R&D, and entrepreneurship, with particular attention paid to the role of tertiary education to create the foundational basis for selecting the variables to be included in the IRE index, we focused on the following points:

1. *Analysis of the 2021 "Regional Innovation Scoreboard"*. We examined the latest version of the Regional Innovation Scoreboard (RIS) (European Commission, 2021) to assess the performance of innovation systems across 240 regions from 22 EU Member States. The list of selected countries was expanded to include Norway, Serbia, Switzerland, and the United Kingdom. Cyprus, Estonia, Latvia, Luxembourg, and Malta were also considered, as in these countries, the Nomenclature of territorial units for statistics (NUTS) 1 and NUTS 2 levels are identical to the country's territory (European Commission, 2021).

2. *Selection of an ad-hoc set of indicators from the "Regional Innovation Scoreboard" 2021*. We selected at least one indicator most closely related to young and student entrepreneurship from the four main types of activities - Framework conditions, Investments, Innovation activities, and Impacts. The six indicators selected from RIS 2021 are reported in Table 1. It is worth noting that proxies for EIS indicators are included for all enterprises (European Commission, 2021).

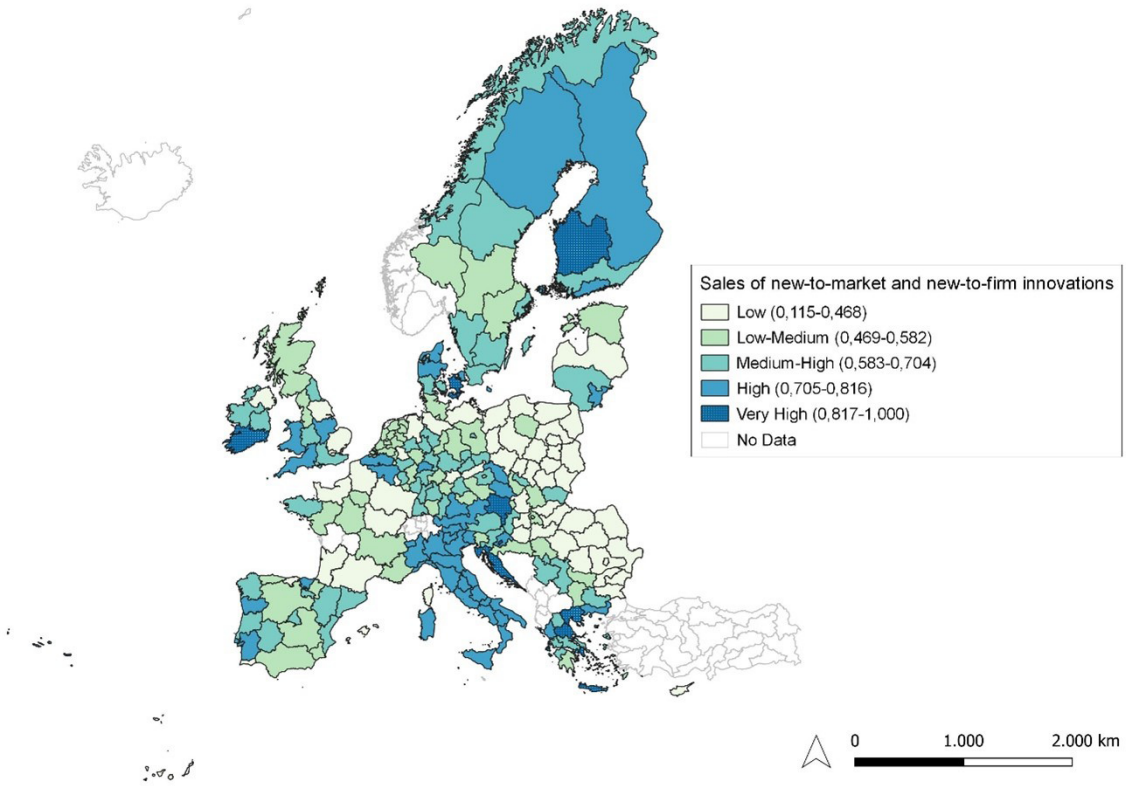

Figure 6. Sales of new-to-market and new-to-firm innovations. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

The indicators highlighted in the previous paragraph were related to administrative areas generally comparable to the NUTS 2 administrative level. However, they have been adjusted and selected to be homogeneous in terms of the indicators calculated. NUTS 2 level data were mapped particularly for mainland Europe and islands, not considering, therefore, overseas dominions and including non-EU member states such as the UK, Norway, and Switzerland. The IRE indicators, as highlighted in the following sections, as well as GDP and population data, among others, were retrieved and homogenized in time – referred to 2021 – and in currency – data were expressed in Euro.

From EU GISCO databases, geographical data were derived and acted as the basis for the computation of the different elaborations. The data consisted of a selection and combination of NUTS 1 and NUTS 2 levels – and similar - administrative units, where ad-hoc indicators were attributed, analyzed and mapped. A total of 245 units were used in the analysis. Data regarded EU countries together with the UK and Switzerland.

3.1. Creation of the composite index Innovation Readiness Environment (IRE)

We applied the *Mazziotta-Pareto* composite index to summarize the data of the mathematical combination of the selected indicators to create the composite index "Innovation Readiness Environment" (IRE) that represents, with a single score, the overall performance measured by the six indicators (Mazziotta & Pareto, 2013; Mazziotta & Pareto, 2018). We conceived it as a synthesis of all indicators to assess the overall performance (as opposed to a single-indicator performance) of the European Regions.

The MPI can be employed to compare inequality levels across different regions, periods, or social groups, and it can also be used to evaluate the impact of specific policy interventions on inequality patterns.

The MPI building proceeds in the following two stages:

1) Normalization

Let $X = x_{ij}$ be the matrix with n rows (countries or geographical areas) and m columns (indicators), and let M_{xj} and S_{xj} denote the mean and the standard deviation of the j-th indicator:

$$M_{x_j} = \frac{\sum_{j=1}^{n} x_{ij}}{n} \qquad S_{x_j} = \sqrt{\frac{\sum_{j=1}^{n} (x_{ij} - M_{x_j})^2}{n}}.$$

The standardized matrix $Z = z_{ij}$ is defined as follows:

$$z_{ij} = 100 \pm \frac{(x_{ij} - M_{x_j})^2}{S_{x_j}} 10$$

where the sign ± depends on the relation of the j-th indicators with the phenomenon to be measured (+ if the individual indicator represents a dimension considered positive and - if it represents a dimension considered negative).

2) Aggregation

Let cv_i be the coefficient of variation for the i-th units:

$$cv_i = \frac{S_{z_j}}{M_{z_j}}$$

where

$$M_{z_j} = \frac{\sum_{j=1}^{n} z_{ij}}{n} \qquad S_{z_j} = \sqrt{\frac{\sum_{j=1}^{n} (z_{ij} - M_{z_j})^2}{n}}.$$

Then, the generalized form of MPI is given by:

$$MPI^{\pm} = M_{z_j}(1 \pm cv_i^2) = M_{z_i} \pm S_{z_i} cv_i$$

where the sign of the penalty (the product S_{zi} cv_i) depends on the kind of phenomenon to be measured and then on the direction of the individual indicators (De Muro *et al.*, 2008).

If the indicator is increasing or positive, *i.e.* increasing values of the indicator correspond to positive variations of the phenomenon, then MPI^{-} is used. Vice versa, if the indicator is decreasing or negative, *i.e.* increasing values of the indicator correspond to negative variation of the phenomenon, then MPI^{+} is used.

Given our phenomenon, the MPI is calculated with the negative sign.

Thus, in our IRE index, created using the Mazziotta-Pareto formula shown above, the indicators previously reported in Table 1 co-influence, and with reference to Figure 7, the results show only 11 European countries ranking very high in innovation performance, followed by 44 high-performing countries, 60 (medium-high), 66 (medium-low) and, finally, 64 (low).

3.2 An analytical view of IRE as a predictor of innovation

To understand the indicator's potential, it was decided to perform an analysis of spatial clustering of the same indicator, as well as an exam of a possible relationship between IRE and GDP. This set of analyses involved relying on different tools for performing such tasks as the linear regression and LISA methods.

Linear regression. A linear regression was performed, considering a potential relationship between the IRE and other elements that can be considered relevant, such as the GDP. The analysis was performed using Apache OpenOffice 4.1.14 CALC suite. A regression analysis was performed on the study area, and the spatial units were considered. The linear regression attempts to model the relationship between the two variables by fitting a linear equation to observed data. The function calculates the statistics for a line using the least squares method to calculate a straight line that best fits data and then returns

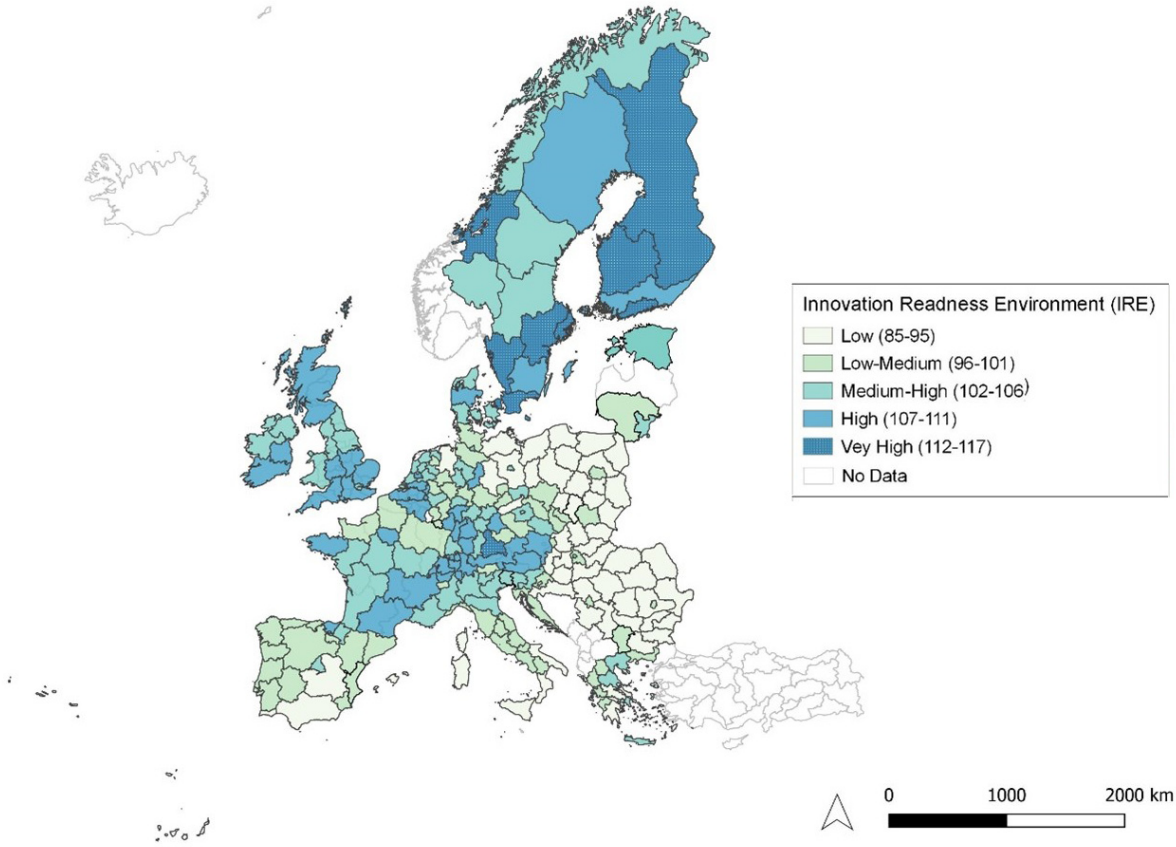

Figure 7. Innovation Readiness Environment. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Silvia Battino.

an array that describes the line. This method calculates the best-fitting line for the observed data, minimizing the sum of the squares of the vertical deviations from each data point to the line.

The general equation for the line is:

$$Y = aX + b$$

Where X is the explanatory variable, and Y is the dependent variable. The slope of the line is b, and a is the intercept (the value of y when x = 0).

Autocorrelation and LISA. Since the data is considered spatial in its extent, Exploratory Spatial Data Analysis (ESDA) appears paramount in observing the related phenomena in its territorial component. Spatial clustering methods are useful for making sense of complex geographic patterns (Anselin, 1995). Events in space, in fact, are rarely randomly distributed but present, instead, a certain degree of local similarity among them. Regions in space, particularly, tend to have features locally similar, fading as distance increases or, as Tobler (1970) "all things are related, but nearby things are more related than distant ones". Data can, in fact, mutually influence geographical shape and, spatial proximity and values attributed to the same units. That means observing a selected variable's behaviour in relation to its position in space and proximity. Such a characteristic is known as spatial autocorrelation. The most interesting property of spatial autocorrelation is the capability to analyze at the same time locational and attribute information (Goodchild, 1986; Lee & Wong, 2001) defined spatial autocorrelation as follows:

$$SAC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}\, w_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

Where:

1. n is the number of objects;
2. i and j are two objects;
3. x_i is the value of object i attribute;

4. c_{ij} is a degree of similarity of attributes *i* and *j*;

5. w_{ij} is a degree of similarity of location *i* and *j*;

if $c_{ij} = (x_i - \bar{x})(x_j - \bar{x})$ Moran Index I (Moran, 1948; O'Sullivan & Unwin, 2010) can be defined as follows:

$$I = \frac{N\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{(\sum_i \sum_j w_{ij})\sum_i (x_i - \bar{x})^2}$$

Moran I and Geary's G, not considered here, represent a global indicator of spatial autocorrelation, which is considered in the overall study region. Local variations are better observed by means of local indicators of spatial association; in particular, the local moran index makes it possible to evaluate the similarity of each observation with nearby geographical objects for each position. This can be seen as the sum of all local indices and is proportional to the value of the Moran one:

$$I_i = \frac{(X_i - \bar{X})}{S_x^2}\sum_{j=1}^{N}(w_{ij}(X_j - \bar{X}))$$

Where:

- N is the number of geographical units;
- X_i is the variable describing the phenomenon under investigation in region i;
- $\bar{X}$ represents the sample average and $(X_i - \underline{X})$ it is the variable's average deviation;
- S_x^2 is the Standard deviation;
- w_{ij} is the weight matrix.

The area units considered need to be weighted by means of a contiguity matrix, reproducing the spatial relationship among the regions considered, using a binary set of existing / non-existing contiguity among the different areas, following a 'Queen rule' of connection (Anselin, 1995).

From the application of the above-mentioned method, it is possible to obtain five combinations:

(1) high values of the phenomenon and high levels of similarity with the nearby areas, known hot spots (High-High), observable on the upper right quadrant of the global Moran's I graph;

(2) low values of the phenomenon and low levels of similarity with the nearby areas, called cold spots (Low-Low); observable on the lower left quadrant of the global Moran's I graph

(3) high values of the phenomenon and low levels of similarity with the nearby areas are detected, referred to as potential outliers (High-Low);

(4) low values of the phenomenon and high levels of similarity with nearby areas are highlighted, referred to as potential outliers (Low-High);

(5) no significant autocorrelation values are detected (Not Significant).

Spatial autocorrelation can also be considered bivariate, typically as the correlation between one variable and the spatial lag of another variable. In the case considered, the implemented indicator, IRE, was related to measures of local GDP to understand the possible relationship among the different variables and their spatial extent. Recently, LISA's local Moran's I was used to analyze, among others, socio-economic phenomena on area unit data on various applications, from migration movements (Borruso, 2009; Murgante & Borruso, 2012) to the efficacy of cohesion policies (Balletto *et al.,* 2020). The analysis was performed using GeoDA as Free and Open Source Software developed by Anselin (1995).

4. Results

IRE applied to the 245 European NUTS 1 and NUTS 2 units was considered to be related to per capita GDP values in € in 2021. A set of analyses were performed, as anticipated in the above-mentioned methods. Namely, the regression analysis and the Local Moran over the IRE index. As an early visual observation of the IRE maps realized that they portrayed a certain level of similarity of most innovative regions with the highest GDP's ones, as those of the European core or the heart of the so-called 'Blue Banana' (Brunet, 1989), a regression analysis was initially carried out to observe if a certain relationship among the variables could be considered. IRE and GDP values were plotted, and a linear regression was performed, providing interesting results given the high level of relation that can be observed among the different variables (R^2 of 0.525; Figure 8 a) in the direct relationship, and better fitting values considering Ln GDP (R^2 of 0.6256; Figure 8 b).

Such initial results made us consider the spatial component and behaviour of both IRE and its relationship with European GDP. As in the previous paragraph, Global and Local Moran's I were performed on IRE (Figure 9 and Figure 10), Ln GDP (Figure 11 and Figure 12) and as a cross, bivariate Moran's I on IRE and Ln GDP (Figure 13 and Figure 14).

Local Moran's application presents spatial clusters of high-high autocorrelation of the IRE in the NUTS areas in proximity of the European core, covering from Eastern France, Southern Germany, part of Austria and Belgium, and most of England units. Scandinavian peninsula's units represent a relevant cluster as well. Negative autocorrelation can be observed on a wide cluster of units belonging to Eastern European countries and on one in Southern Spain (Figure 9).

Cluster map appears significant, with a relevant value of Moran's I (0,708; Figure 10 a and b).

Univariate local Moran's I was also performed on Ln GDP, reporting a – quite expectable – autocorrelation and spatial clustering of areas in the European economic core, rooted into Northern Italian Regions and extended northwards through Southern and Western Germany, Eastern France, BeNeLux

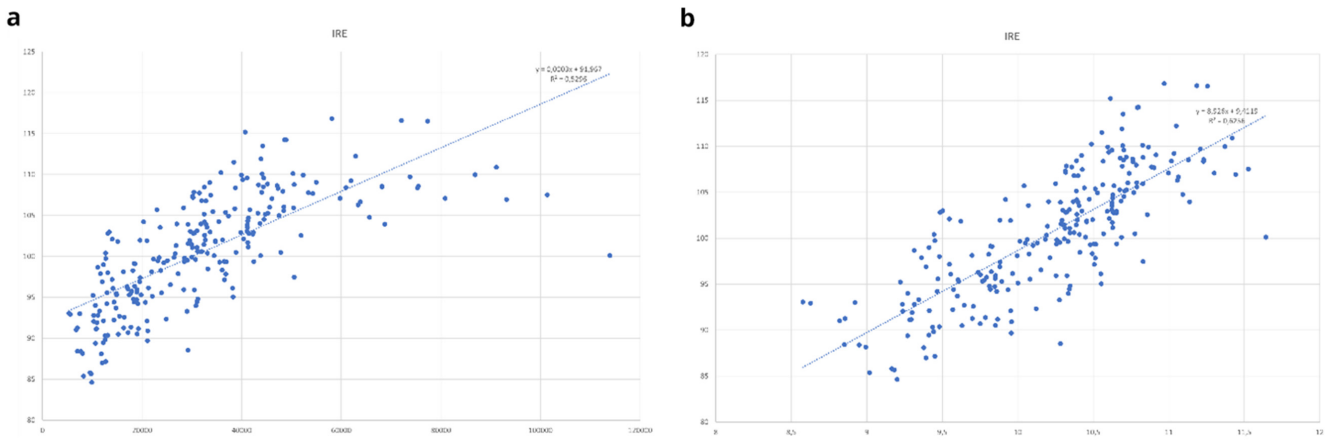

Figure 8. Regression Analysis **a**) IRE and GDP; **b**) IRE – Ln GDP. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Graph by Giuseppe Borruso.

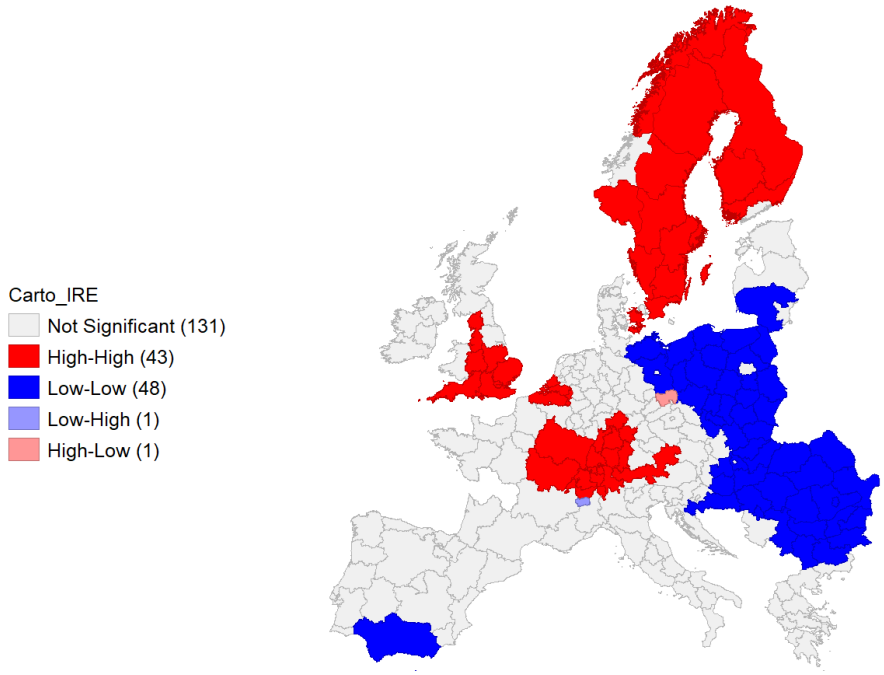

Figure 9. Local Moran's I Cluster Map on IRE. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Giuseppe Borruso.

and Ireland. Scandinavian regions represent another cluster. An East-West division appears with a wide cluster of negative autocorrelation regarding the regions belonging to Eastern European countries (Figure 11).

Also, the cluster map appears significant in this case, with a relevant value of Moran's I (0,788; Figure 12 a and b).

A final analysis was performed employing a bivariate local Moran's I, comparing IRE and Ln GDP (Figure 13). As bivariate local Moran's I describes the statistical relationship between the first variable at a given location and the spatially lagged second variable at neighbouring locations, the 'high – high' values (red) represent the spatial autocorrelation of the area units (also observable in the upper right quadrant

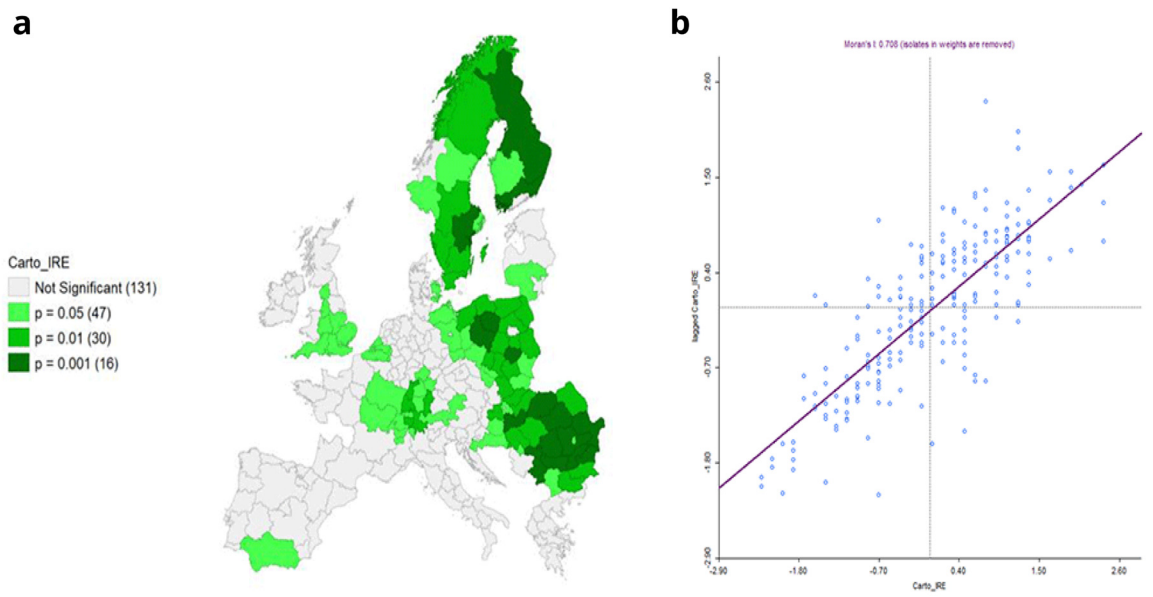

Figure 10. a) Local Moran's I Significance map on IRE and **b**) Moran's I. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map and graph by Giuseppe Borruso.

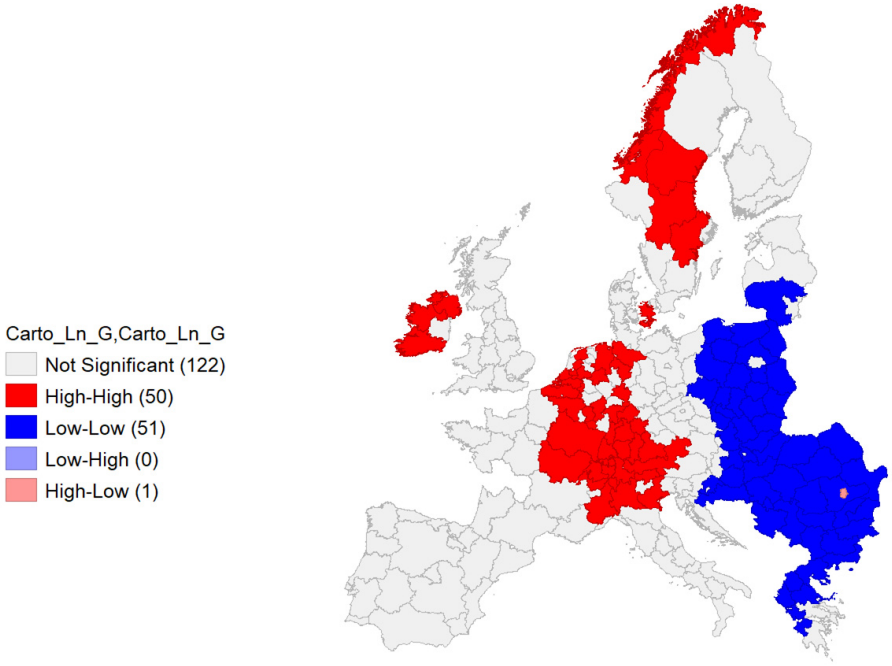

Figure 11. Local Moran's I Cluster Map on Ln GDP. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Giuseppe Borruso.

of the Moran's I graph, Figure 14 b), characterized by high values of IRE, spatial contiguity, and high values of Ln GDP. An interesting picture can be observed, with clusters of NUTS areas in the Central and Southern parts of the European core – Southwestern Germany, Western France, Southern Austria – Belgian NUTS and most of England Units.

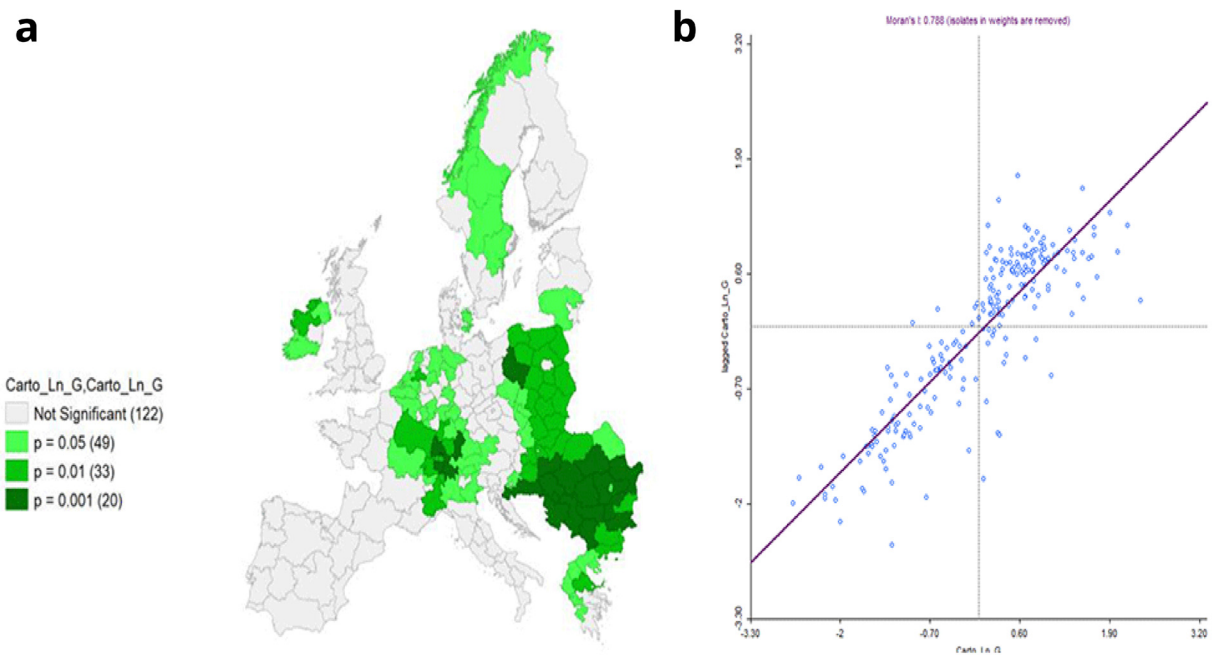

Figure 12. a) Local Moran's I Significance map on Ln GDP and **b**) Moran's I. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map and graph by Giuseppe Borruso.

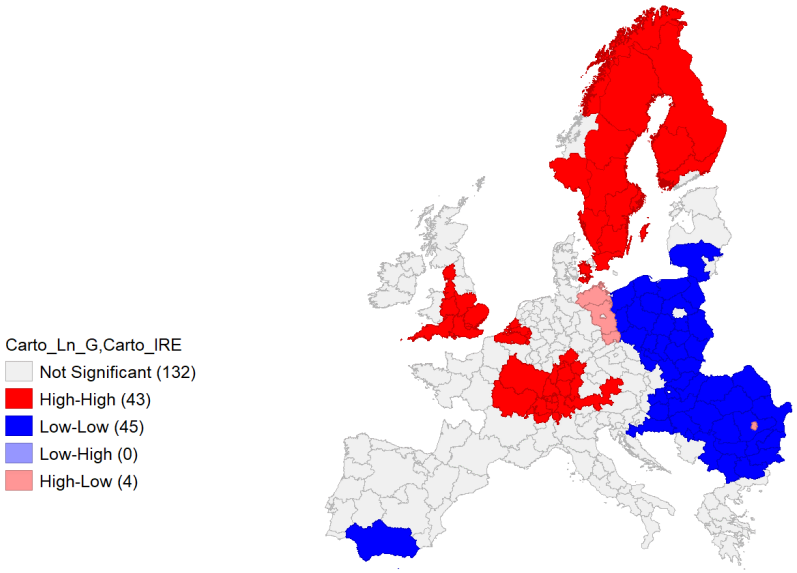

Figure 13. Bivariate Local Moran's I Cluster Map on IRE & Ln GDP. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map by Giuseppe Borruso.

Scandinavian NUTS represent a relevant cluster as well. Negative spatial autocorrelation covers a relevant part of Eastern European Countries' NUTS.

The results from the bivariate local Moran's I computation can be considered significant (Figure 14 a and b) with a relevant value of Global Moran's I (0.672).

5. Conclusions

In the evolving discourse on the spatial dynamics of innovation clusters within European regions, it is crucial to highlight the critical role of the newly developed Index of Regional Entrepreneurship (IRE) in outlining the intricate patterns and associations with per capita GDP distributions.

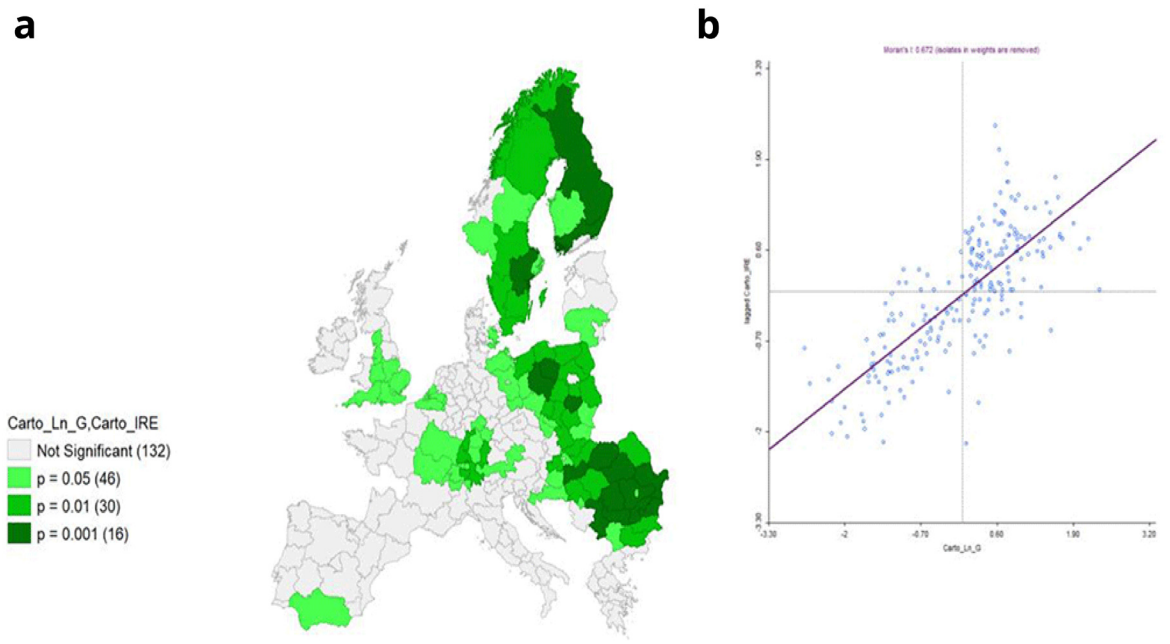

Figure 14. a) Bivariate Local Moran's I Significance map on IRE & Ln GDP and **b**) Moran's I. Source: elaboration from GISCO – Eurostat data; Data as in Table 1. Map and graph by Giuseppe Borruso.

If it is true that a European core tend to be quite settled and consolidated as in the Brunet (1989) Blue Banana metaphor, innovation tend to follow partly similar patterns but also other, more specific ones. Focusing on the British Isles and the Scandinavian peninsula, the IRE index serves as an invaluable tool for nuanced exploration of different regional policy frameworks, revealing institutional and structural dimensions beyond GDP narratives.

Weaving this analysis into the current literature requires an alignment with the objectives of Entrepreneurship 2020. The strategy is based on three pillars, all of which reflect on the IRE index: a robust framework for entrepreneurial education and training, promoting an environment ripe for entrepreneurial growth, and cultivating role models to unleash the latent entrepreneurial capacity within different social groups.

Strengthening entrepreneurial education and training is central to this strategy, representing a key investment to enhance Europe's position in the global entrepreneurial landscape. In this context, the IRE Index emerges as a cornerstone that allows for a deeper understanding of the region-specific nuances that influence entrepreneurial developments, as outlined in the writings of Jenner (2012) and in the guidelines that are encapsulated within the DG EAC - ET2020.

However, Benneworth and Osborne (2015) argued that the untapped potential in entrepreneurship education is largely due to inadequate integration within university knowledge frameworks. Thus, the IRE Index can act as an analytical tool, guiding research efforts to synergize entrepreneurial initiatives with university knowledge, fostering the ecosystem where entrepreneurial attitudes can be developed. Simultaneously, the rapidly evolving global knowledge and technology landscape highlighted by Posselt *et al.* (2019) requires a proactive stance in advancing entrepreneurial universities capable of navigating this complexity. IRE Index, in this regard, is emerging as a tool to guide universities in fostering leadership and innovation, thus, realizing Entrepreneurship 2020 Action Plan's vision that supports sustainable economic growth and development in a coherent and inclusive way.

Synthesizing these findings within the broader framework of the 2030 Agenda for Sustainable Development (SDG), the IRE Index is seen as a central tool for improving societal wellbeing, particularly for disadvantaged groups. The relationships between entrepreneurship and the SDG, in particular Goals 4.4 and 8.3, comes alive through the lens of the IRE Index, providing critical evidence on the role of entrepreneurship in fostering skills development and innovation, an, as a result, inclusive growth. Besides, promoting entrepreneurship, prosperity and wellbeing across Europe requires taking into account regional differences and a deeper understanding of regional innovation indicators. Using tools such as the Smart Specialisation Strategy (S3) and the Smart Specialisation Strategies for Sustainable and Inclusive Growth (S4), the IRE Index provides an in-depth understanding of regional entrepreneurial trends to guide future research and policy directions. As we explore the complex spatial dynamics of innovation clusters within European regions, integrating sustainability into governance

mechanisms, as detailed by Radosevic and Soete (2023) and creating value networks, Wostner (2017), offers a critical perspective that complements our analysis. The governance challenges identified by the authors, including the need for new forms of governance that emphasize reflexive and experimental approaches, align with the findings derived from the IRE index, highlighting how entrepreneurship and innovation are not just correlated with economic outputs like GDP but also with sustainable regional development practices and the creation of value networks, both vertical and international. The integration of sustainability dimensions in smart specialization strategies provides a foundational approach to understanding and enhancing the regional entrepreneurial ecosystems mapped by the IRE index. This integration is essential for achieving the 2030 Agenda for Sustainable Development and specifically supports Goals 4.4 and 8.3 by promoting skills development and sustainable innovation.

While IRE provides insights into the dynamics of innovation clusters in European regions, several limitations and avenues for future research emerge. First, although the IRE index is comprehensive, it focuses on certain indicators, such as R&D spending, patent rate, firm size, and educational levels. As a result, it may not capture all relevant factors influencing regional innovation and entrepreneurship. Future research could expand the index by including additional dimensions, such as Gross Expenditure on Research and Development (GERD), to provide a more holistic understanding of innovation ecosystems. In addition, technological progress and its impact on entrepreneurial activity have been overlooked. By integrating technological aspects, such as measures of technology adoption, digitalization levels, or investment in new technologies, future research can provide a broader understanding of factors driving innovation and entrepreneurship in European regions.

Furthermore, IRE's reliance on existing policy framing, such as the Entrepreneurial 2020 Action Plan and Smart Specialisation Strategies, may not fully capture regional innovation ecosystems' dynamic and complex nature. A comparative analysis between the IRE index and alternative frameworks or methodologies could be applied for future research to overcome this limitation. In addition, the inclusion of longitudinal data and qualitative research methods such as case studies and interviews with key stakeholders could be used to gain insights into the contextual factors shaping regional dynamics.

Ethics and consent

Ethical approval and consent were not required.

Data and software availability

The dataset is available at the following link:

Figshare: EIS Data 2021. https://doi.org/10.6084/m9.figshare.24459265.v2 (Fabbro *et al*., 2023)

The dataset encompasses the year 2021 from European Innovation Scoreboard (EIS) 2021 Database and focuses on European Union countries, specifically addressing the following indicators: 1.1.2, 1.1.3, 2.2.1, 3.2.1, 3.3.1, 4.2.3.

Free and Open Source Software was used for realizing maps (QGIS 3.24, https://www.qgis.org/), linear regression (CALC from Apache OpenOffice 4.1.14, https://www.openoffice.org/), Local Indicator of Spatial Association (GeoDA 1.22, https://geodacenter.github.io/).

Source data

The data presented herein are extracted from the European Innovation Scoreboard (EIS) 2021 Database, which is publicly accessible at the following URL: https://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/european-innovation-scoreboard/eis

Documentation pertaining to the dataset is accessible via the following URL: https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

Individual contributions

For Prof. Silvia Battino, in addition to his contributions outlined in the Credit Author Statement, it is specified that she undertook the collection and harmonization of spatial data and the realization of maps as in figures from 1 to 7.

For Prof. Giuseppe Borruso, in addition to his contributions outlined in the Credit Author Statement, it is specified that he undertook the collection and harmonization of data pertaining to Gross Domestic Product (GDP), utilized GeoDA software for spatial data analysis utilized GeoDA Free and Open Source Software for spatial data analysis, and conducted regression analyses. Furthermore, he performed Local Indicator of Spatial Association (LISA) analyses and contributed interpretive comments on the aforementioned elements together with the realization of figures from 8 to 14.

Acknowledgements

We would like to mention the specific case of the region we are based in, i.e. Friuli Venezia Giulia (FVG) in Italy, as an example of how the reasoning developed throughout this paper can become factual in specific and concrete terms when it comes to establishing a conceptual link between the territorial peculiarities of a given region with the awareness about the existence of competitors represented by the other European regions (Smart Specialisation Strategy (S3) of Friuli Venezia Giulia Region).

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Open Peer Review

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Version 1

Reviewer Report 17 April 2024

https://doi.org/10.21956/openreseurope.18166.r37926

✔ **Maja Basic**
Faculty of Economics and Business, University of Zagreb, Zagreb, Croatia

Thank you for the opportunity to read and evaluate your works. It is an interesting study that speaks about the relationship between innovation, R&D, and entrepreneurship in European nations, emphasizing the role of tertiary educational institutions. It introduces the Innovation Readiness Environment (IRE) index to evaluate regional innovative capabilities, highlighting the importance of higher education in fostering entrepreneurial success and suggesting targeted policy interventions.

The IRE Index is a novelty and an interestingly presented index. Attempts have been made to compose the index, especially in organisations and not so much in locally or regionally (apart from the mentioned Regional Innovation Scoreboard). Hence, this index presents a valuable novelty to the research on entrepreneurship and innovation.

Moreover, it soundly connects the concepts of the index to the SDGs and the Entrepreneurship 2020 Action Plan.
The methodology is sound and accounts for a new approach to measuring the innovation activities.

The only minor drawback is incorporation of aspects of the Regional Innovation Indicators without further attempt to include different perspective such as the usage of GERD, especially significant in the former socialist countries, and furthering this index into different categories. This is a suggestion for further research. E.g., by using the study of Yoruk, Radosevic and Fisher (2023) or Radosevic and Soete (2023) to gain additional insights and connect the technology trajectory to entrepreneurship.

Is the work clearly and accurately presented and does it engage with the current literature?
Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

Are all the source data and materials underlying the results available?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: innovation, internationalisation, competitiveness

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 11 Jun 2024

Giacomo Marzi

Comment 1: Thank you for the opportunity to read and evaluate your works. It is an interesting study that speaks about the relationship between innovation, R&D, and entrepreneurship in European nations, emphasizing the role of tertiary educational institutions. It introduces the Innovation Readiness Environment (IRE) index to evaluate regional innovative capabilities, highlighting the importance of higher education in fostering entrepreneurial success and suggesting targeted policy interventions.
The IRE Index is a novelty and an interestingly presented index. Attempts have been made to compose the index, especially in organisations and not so much in locally or regionally (apart from the mentioned Regional Innovation Scoreboard). Hence, this index presents a valuable novelty to the research on entrepreneurship and innovation.
Moreover, it soundly connects the concepts of the index to the SDGs and the Entrepreneurship 2020 Action Plan.
The methodology is sound and accounts for a new approach to measuring the innovation activities.
The only minor drawback is incorporation of aspects of the Regional Innovation Indicators without further attempt to include different perspective such as the usage of GERD, especially significant in the former socialist countries, and furthering this index into different categories. This is a suggestion for further research. E.g., by using the study of Yoruk, Radosevic and Fisher (2023) or Radosevic and Soete (2023) to gain additional insights and connect the technology trajectory to entrepreneurship.

Response: Thank you for your thoughtful review of our study. We value your feedback and constructive suggestions for future research. Your insights have been carefully considered

and integrated into the section on limitations and future research directions. Your contribution has greatly enriched our work, and we are grateful for your valuable input.

Competing Interests: No competing interests were disclosed.

Reviewer Report 20 February 2024

https://doi.org/10.21956/openreseurope.18166.r37933

Leonardo Boncinelli
University of Florence, Florence, Italy

Summary
This study makes a significant contribution to understanding the interplay between innovation, R&D, and entrepreneurship across European regions. The introduction of the IRE index is a noteworthy advancement in measuring regional innovation capabilities.

Suggestions
The manuscript would be enhanced by a more thorough comparative analysis with the existing body of literature. Additionally, it would benefit from an expanded exposition on the criteria employed for the selection of indicators. Establishing a more robust linkage between the constructed index and its implications for policy-making and economic growth, while concurrently acknowledging its present constraints, would markedly augment the contribution of this paper. Addressing these aspects would not only sharpen the study's impact but also amplify its significance

A. Clarity and Engagement with Current Literature
Answer: Yes/Partly
The abstract and introduction indicate a clear attempt to engage with the current literature on innovation, R&D, and entrepreneurship. The inclusion of a novel metric, the Innovation Readiness Environment (IRE) index, suggests an effort to contribute to the existing body of knowledge. However, the depth of engagement with current literature could be further elaborated upon to demonstrate how this work builds upon or diverges from existing research findings.
Recommendations:
- Enhance the literature review section by comparing and contrasting the IRE index with other existing metrics in innovation studies (e.g., GII & EIS).
- Sketch out (verbally) a theoretical framework that interconnects the various components of the IRE index, to provide a more comprehensive understanding of the overarching context.

B. Study Design and Technical Soundness
Answer: Yes

The study design, focusing on the development and application of the IRE index across European nations, seems appropriate for addressing the research objectives. The methodology section describes a thorough process for selecting variables, creating the composite index, and analyzing the data, which supports the work's technical soundness.

C. Details of Methods and Analysis for Replication
Answer: Yes/Partly
While the methodology for creating the IRE index and conducting analyses is detailed, the description could benefit from more specific information on the selection of the indicators.
Recommendation:
- Expand upon the descriptions of the data sources utilized in the study, delineating any limitations or potential biases associated with these sources; furthermore, elucidate the rationale behind the selection of the specific indicators included in the IRE index.

D. Availability of Source Data and Materials
Answer: Yes
The article provides a DOI for accessing the dataset. This transparency in data availability is commendable and supports the reproducibility of the research.

E. Statistical Analysis and Interpretation
Answer: Yes/Partly
The study employs appropriate statistical analyses, including linear regression and spatial clustering methods. However, the interpretation of these analyses could be enhanced by discussing the implications of the findings in a broader economic and societal context.
Recommendation:
- Discuss the statistical significance of the findings and their practical implications for policymakers and stakeholders in the innovation ecosystem.

F. Support of Conclusions by Results
Answer: Yes/Partly
The conclusions drawn about the importance of tertiary education and the regional specificity of innovation activities are supported by the results. However, the direct impact of the IRE index on policy formulation and economic growth could be further substantiated with empirical examples or case studies.
Recommendation:
- Discuss any limitations of the study and how future research could address these gaps.

Is the work clearly and accurately presented and does it engage with the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

Are all the source data and materials underlying the results available?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Behavioral economics; Experimental economics; Game theory

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 11 Jun 2024

Giacomo Marzi

Comment 1: **Summary**
This study makes a significant contribution to understanding the interplay between innovation, R&D, and entrepreneurship across European regions. The introduction of the IRE index is a noteworthy advancement in measuring regional innovation capabilities.
Response: We believe that the IRE Index provides valuable insights for policymakers and stakeholders to facilitate more effective promotion of innovation and entrepreneurial activities. Your encouraging comments motivate us to continue refining and expanding our research to increase its impact and practical applications in this area.
Comment 2:
Suggestions
The manuscript would be enhanced by a more thorough comparative analysis with the existing body of literature. Additionally, it would benefit from an expanded exposition on the criteria employed for the selection of indicators. Establishing a more robust linkage between the constructed index and its implications for policy-making and economic growth, while concurrently acknowledging its present constraints, would markedly augment the contribution of this paper. Addressing these aspects would not only sharpen the study's impact but also amplify its significance.
Response: In response, we have extended our literature review to include a more thorough comparative analysis with existing metrics such as the Global Innovation Index (GII), European Innovation Scoreboard (EIS), Regional Innovation Scoreboard (RIS), Global Entrepreneurship Index (GEI), OECD Science, Technology and Industry Scoreboard. We have also provided a more detailed explanation of the criteria used to select the indicators and clarified the rationale for their inclusion. In addition, we have provided a more robust link between the IRE index and its implications for policymaking and economic growth. We have acknowledged the current limitations of the index and suggested future research directions to address these gaps. These improvements have increased the impact and relevance of the study.
Comment 3:
A. Clarity and Engagement with Current Literature

Answer: Yes/Partly
The abstract and introduction indicate a clear attempt to engage with the current literature on innovation, R&D, and entrepreneurship. The inclusion of a novel metric, the Innovation Readiness Environment (IRE) index, suggests an effort to contribute to the existing body of knowledge. However, the depth of engagement with current literature could be further elaborated upon to demonstrate how this work builds upon or diverges from existing research findings.
Recommendations:
- Enhance the literature review section by comparing and contrasting the IRE index with other existing metrics in innovation studies (e.g., GII & EIS).
- Sketch out (verbally) a theoretical framework that interconnects the various components of the IRE index, to provide a more comprehensive understanding of the overarching context. ***Response:*** We have taken on board your recommendations to improve clarity and engagement with the current literature. In particular, we have expanded the literature review section to include a brief overview of other existing metrics in innovation studies, such as the Global Innovation Index (GII), the European Innovation Scoreboard (EIS), the Regional Innovation Scoreboard (RIS), the Global Entrepreneurship Index (GEI), and the OECD Science, Technology and Industry Scoreboard. To provide a more comprehensive understanding of the overarching context, we have also outlined a theoretical framework that links the different components of the IRE index.

Comment 4:

B. Study Design and Technical Soundness
Answer: Yes
The study design, focusing on the development and application of the IRE index across European nations, seems appropriate for addressing the research objectives. The methodology section describes a thorough process for selecting variables, creating the composite index, and analyzing the data, which supports the work's technical soundness.
Response: We appreciate your acknowledgment of the appropriateness of the study design and the thoroughness of the methodology section. Our aim was to develop and apply the IRE index effectively across European countries, and we are pleased that you found our approach appropriate for achieving the research objectives. Thank you for recognising these aspects of our study.

Comment 5:

C. Details of Methods and Analysis for Replication
Answer: Yes/Partly
While the methodology for creating the IRE index and conducting analyses is detailed, the description could benefit from more specific information on the selection of the indicators.
Recommendation:
- Expand upon the descriptions of the data sources utilized in the study, delineating any limitations or potential biases associated with these sources; furthermore, elucidate the rationale behind the selection of the specific indicators included in the IRE index. ***Response:*** We have taken steps to address your suggestion by enhancing the methodology section to provide more specific information on indicator selection.

Comment 6:

D. Availability of Source Data and Materials
Answer: Yes
The article provides a DOI for accessing the dataset. This transparency in data availability is

commendable and supports the reproducibility of the research. ***Response:*** We appreciate your recognition of the transparency of data availability demonstrated in our article. We are committed to maintaining this standard of transparency to facilitate replication and verification of our findings.

Comment 7:

E. Statistical Analysis and Interpretation

Answer: Yes/Partly

The study employs appropriate statistical analyses, including linear regression and spatial clustering methods. However, the interpretation of these analyses could be enhanced by discussing the implications of the findings in a broader economic and societal context.

Recommendation:

- Discuss the statistical significance of the findings and their practical implications for policymakers and stakeholders in the innovation ecosystem. ***Response:*** Thank you for your feedback. We acknowledge that although our study makes use of appropriate statistical analyses, there is still room for improvement in the interpretation of these analyses. Following your recommendation, we have added a discussion of the statistical significance of the findings and their practical implications for policymakers and innovation ecosystem stakeholders in the Conclusions section. ***Comment 8:***

F. Support of Conclusions by Results

Answer: Yes/Partly

The conclusions drawn about the importance of tertiary education and the regional specificity of innovation activities are supported by the results. However, the direct impact of the IRE index on policy formulation and economic growth could be further substantiated with empirical examples or case studies.

Recommendation:

- Discuss any limitations of the study and how future research could address these gaps. ***Response:*** Thank you for your comments! We appreciate your insightful input, which contributes to a deeper understanding of the implications of our study. We have addressed the limitations of the study and provided insights into how future research could fill these gaps in response to your recommendations.

Competing Interests: No competing interests were disclosed.