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SDG9 and the competitiveness: Employing mixed methods to understand how countries can use science to compete☆

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ABSTRACT

Policymakers seek the best ways to promote the development of their countries. With Agenda 2030 at the top of the conversation, this study aimed to analyze the relationship between SDG9 and GCI. The study uses two methodologies, the first of which uses panel data to explain how variables that make up SDG9 explain competitiveness across countries in the Eurozone from 2010 to 2019. A second approach is through qualitative methodology (fsQCA) to verify the differences in the possible combinations of variables for the same outcome – higher values of competitiveness.

The findings suggest that R&D and patents are two factors that increase competitiveness. Additionally, the number of patents filed in each country is also considered a necessary condition for high GCI values, reinforcing the need for countries to protect their innovations.

In conclusion, the variables of SDG9 show significant relationships to achieve high values of competitiveness and that there is not only one solution to achieve the outcome but several, and it is up to policymakers to define which strategy best fits their reality.

The originality of the article lies in the way different methods are combined and the increased capacity to understand the reality that these different methods allow.

1. Introduction

Facing the age of sustainable development (Tipu, 2021), the United Nations (UN) adopted a plan of action for people, the planet, and prosperity–the 2030 Development Agenda "Transforming our world: the 2030 Agenda for Sustainable Development". This action plan will be implemented by all countries and stakeholders working in collaborative partnerships with the UN (General Assembly, 2015). On January 1, 2016, the 17 Sustainable Development Goals (SDGs) announced in this agenda became the main reference point for the development of policies and the drive for sustainable development in all dimensions (Kynčlová et al., 2020).

According to Sachs et al. (2019), the SDGs will require actions by governments, civil society, science, and business to perform the deep transformations essential to achieve the SDGs outcomes. Therefore, evaluating the achievement of countries in meeting the SDGs can be both a challenge and opportunity for stakeholders involved in the implementation of this agenda (Saieed et al., 2021). Performance and progress composite indices are examples of possible options for conducting such a task (Kynčlová et al., 2020; Saieed et al., 2021).

Using indicators from the global indicator framework, the SDG Index and dashboards rank countries in their level of achievement for all SDGs. The overall index reveals the position of a country on average when compared to the best possible result across all 17 SDGs (Kynčlová et al., 2020).

Within the different aims of this Agenda, SDG9 relates to Industry, Innovation, and Infrastructure and aims to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster

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innovation". Even though Innovation has been seen as key to achieving economic growth, SDG9 reinforces this significant role in building sustainable economic prosperity for all societies (Szopik-Depczyńska et al., 2018; Kynčlová et al., 2020).

The relationship between SDG9 and competitiveness has not yet been established; nevertheless, the link between science and competitiveness is often established (van Harmelen et al. (2012)). Five out of ten indicators of SDG9 can be associated with the scientific and technological system and are therefore expected to be related to the countries' competitiveness.

As science and technology are important factors in sustainable development, this study aims to better understand how the components associated with science and technology systems comply with the SDGs and whether they can increase the competitiveness of each country.

The remainder of this paper is organized as follows. In Section 2, the theoretical background of competitiveness and questions associated with science are presented. Section 3 presents the research objectives. Section 4 describes the sample and variables. Sections 5 and 6 present the results of the adopted methodologies (panel data and fuzzy-set Qualitative Comparative Analysis fsQCA), and Section 7 discusses the findings. Finally, Section 8 presents the contributions of this study and concludes the paper.

2. Theoretical background

The literature notes the importance of industrialization in economic development (Ogunmakinde et al., 2022). Fleming and Sorenson (2004) pointed out that, in this process, scientific research is crucial because by stimulating technological innovation, we accelerate economic growth. Therefore, a close relationship between the science system and competitiveness is often established (van Harmelen et al. (2012)).

During this period of transition to a digital and greener economy, the role of science and technology is possibly even more important in the search for solutions that ensure sustainable growth (Capasso et al., 2019; Fernandes et al., 2021; Herman, 2021). Particularly, the role of science and technology is critical to the implementation of the SDGs (Walsh et al., 2020; Pardo Martínez and Cotte Poveda, 2021).

2.1. Sustainable development goals, science and technology

Since their adoption in 2015, SDGs have been a reference for the analysis of sustainable development issues. The 17 SDGs constitute an integrated and complex framework, so the interaction relationships established within this framework between the various SDGs are equally complex. Pradhan et al. (2017) showed that in these interactions, there are both situations of synergy, that is, of mutual benefit – the improvement in one SDG benefits another SDG – and situations of trade-off–the improvement in one SDG harms another SDG. According to Pradhan et al. (2017), SDG 9 is one of the SDGs involved in additional trade-off situations.

The complexity of these interactions leads to complex decision-making processes. The effectiveness of these decision-making processes can be compromised if they are not based on sound systemic frameworks that allow anticipation of adverse/destructive behaviors (Armenia et al., 2022). The scientific community produces a multitude of SDG-relevant data that support decision-making processes. It is also a scientific and technological system that produces solid systemic frameworks to ensure a more effective decision-making process.

Thus, it can be concluded that progress in the SDGs, as well as their monitoring and evaluation, occurs despite the lack of governmental guidance and support (Rocha de Siqueira and Ramalho, 2022), with the scientific and technological system playing a key role in this process.

2.2. The SDG 9 - industry, innovation, and infrastructure

The role of science and technology in the implementation of the SDGs should be seen in multiple dimensions. Strohschneider (2016) stated that science can contribute in two ways to the implementation of the SDGs. On the one hand, by better explaining the interconnections between the sustainable development goals and their underlying challenges, allowing a better understanding of thresholds, effective spillovers, and breakpoints. On the other hand, to support the evaluation of the Sustainable Development Goals and monitor the progress of their achievement.

However, the science, technology, and innovation system itself have its own space, although with only implicit reference (OECD, 2018, p. 96) in terms of SDGs - the SDG 9 "to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation".

SDG 9 functions as a pivotal factor in other SDGs; therefore, Kroll et al. (2019) attributed its synergistic characteristics, that is, an important factor in improving the performance of the other SDGs.

SDG 9 is operationalized through the following ten indicators:

1. Percentage of population using the internet (sdg9_intuse);
2. Scientific and technical journal articles per 1000 population (sdg9_articles);
3. Expenditure on research and development in the percentage of GDP (sdg9_rdex);
4. Researchers per 1000 employed population (sdg9_rdres);
5. Triadic patent families filed per million population (sdg9_patents);
6. Mobile broadband subscriptions (sdg9_mobuse);
7. Logistics Performance Index: Quality of trade and transport-related infrastructure (sdg9_lpi).
8. The Times Higher Education Universities Ranking: average score of the top three universities (sdg9_qs)
9. Gap in internet access by income (sdg9_netacc);
10. Female share of graduates from STEM Fields at the tertiary level (sdg9_womensci).

The first five indicators are associated with the dynamics of the scientific and technological system and are often used as indicators of these dynamics (Kim and Lee (2015) for articles and patents; the Internet use is used by the OECD as one of the metrics of Society and the digital transformation (OECD, 2018); the numbers of scientists and the level of expenditure is used by Żbikowska-Migoń (2001)).

The databases of the last five indicators have missing values; thus, their use would create difficulties in the application of the methods, leading to less robust results. Additionally, methodological issues associated with the fsQCA justify the use of a limited number of indicators. Therefore, only the first five indicators were selected for this study.

2.3. Population using the internet

A knowledge-based economy or society is an information economy or society (Steinmueller, 2002; Nadrljanski and Domitrović, 2014). Information circulates on ICT infrastructure platforms, with a very significant domain of the Internet (Zainab et al., 2002). Many commercial operations are conducted on the Internet. It is through the Internet that many services are carried out - both public (e-government) and private (Internet banking), –and it is through the Internet that more complex and delicate operations such as electronic voting or telemedicine begin to be carried out.

These situations correspond to new functionality for users, but they also correspond to new business opportunities, new possibilities to innovate, and new opportunities to make more evolved uses of the technology. The evolution toward Industry 4.0 and the Internet of Things will accelerate this process even more (Menezes et al., 2021).

Thus, it is with naturalness that we see that the main international rankings related to the scientific and technological system use indicators related to the Internet - be it the European Innovation Scoreboard (European Commission, 2021), the OECD Science, Technology, and

Industry Scoreboard (OECD, 2017), and the Global Innovation Index (WIPO, 2021).

As noted by the European Commission (2021), referring to the European situation, "realizing Europe's full e-potential depends on creating the conditions for electronic commerce and the Internet to flourish" (note that the European Commission's Scorecard uses broadband penetration as opposed to what is used by the Global Innovation Index–Internet usage only, we followed the second option).

2.4. Articles

The number of articles published in each description is an indicator of the performance of a scientific and technological system (i.e., for journal comparisons (Mcguigan et al., 2021); to assess the productivity of scientists (Méndez and Salvador, 1992) to evaluate comparatively different ones (Zhou and Leydesdorff, 2006); and to assess the evolution of science on different continents (Pouris and Pouris, 2009).

The link between the number of published papers and country competition is explored in the literature. Herman (2021) used the number of published articles as a metric to analyze the competitive performance of the most prominent countries in the Southern Hemisphere, and thus, determines how those countries are competing in the innovation and development of environmental technologies.

Horta and Veloso (2007) used metrics related to the number of articles published and the number of citations that these articles obtained, relating these metrics to the competitiveness of countries.

2.5. Patents

Guan and Chen (2012) pointed out that, in this era of the global knowledge economy, technological innovations have become increasingly important for a country's economic growth and competitiveness. Yoon and Kwon (2022) gave competitiveness a technological dimension, measured by the number of patents. Patents issued in a country can be considered the result of investments in new and innovative ideas that contribute to economic success and growth (Hintringer et al., 2021).

The competitiveness provided by patents translates into ascendancy in the market. At the company level, those that cannot process patent information or fail to protect their innovations through the filing of patents lose market competitiveness (Trappey et al., 2012), and, on the contrary, those that manage their patents properly have market gains.

2.6. R&D expenditure

Research funding is therefore a major issue in this regard. Often, funding is public (For e.g.: the case of the COVID-19 vaccine funding in Sampat and Shadlen (2021)). Therefore, public funding agencies are constantly under pressure to justify the amounts they make available for scientific research and the resulting socioeconomic impact (Hu, 2020).

Investment in R&D also has private components, mainly linked to the innovation process, often materialized in new products or processes, and it has been shown that the intensity of this investment is a determining factor for the quantity and quality of patents (Ernst, 1998).

Thus, two components of investment converge in R&D: a public component that contributes to the innovation process by strengthening the common innovation infrastructure and private R&D expenditures associated with a country's technological specialization, and reflecting the country's innovation clusters (Furman et al., 2002).

Investment in research appears to be of great value to competitiveness and should therefore not be neglected (Ernst, 1998). Salman et al. (2020) observed a strong correlation between R&D expenditure and the global competitiveness index (GCI). This is the usual justification for using science policy strategies and national funding programs to increase the international competitiveness of countries (Arnott, 2021).

2.7. Researchers

Like all other production systems, the science and innovation system also requires human resources, mostly scientists. Thus, the number of scientists is often used to determine the ability of a science and innovation system to compete with peers (Hongzhou and Guohua, 1985).

Abt (2007) analyzed over 400,000 papers published over >30 years in the fields of physics, astronomy, geophysics, mathematics, and chemistry, showed that the publication rate of scientific papers depends only on the number of scientists and that there has been no increase in the average annual number of papers published per scientist in these fields. Hintringer et al. (2021) showed that innovation, as measured by the number of patents, is strongly determined by the number of researchers.

Phung et al. (2019) showed that the number of researchers is relevant for the functioning of the science and innovation system and, through it for economic growth during 2006–2014 and involving data from 69 developed and developing countries.

In contrast, the reduction in the number of researchers and the deformation of their age structure has weakened the human component of scientific potential, and is a serious obstacle to the innovation-based reconstruction of Russia's economy and an increase in its competitiveness in the global high-tech market (Zubova, 2012).

This study uses SDG 9 as a framework for analysis, relating its indicators, most associated with the scientific, technological, and innovation system, to competitiveness (Fig. 1). The existing literature supports this framework.

3. Objectives of the study

This study focuses on the Eurozone countries. These countries are subject to the same monetary policy, and the study analyzes their

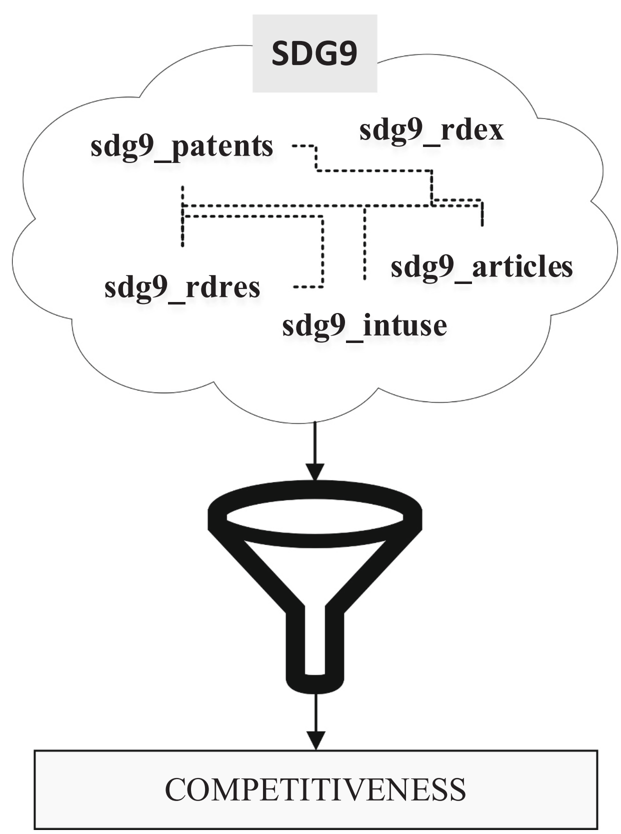

Fig. 1. Theoretical framework.
Source: authors.

capacity for innovation.

This study has two main objectives: The study aims to model the innovation capacity of Eurozone countries using panel data to show, among the variables that make up SDG9, the effect they have on innovation capacity (quantitative analysis) and to perform a qualitative analysis that identifies the paths that lead to innovation capacity (qualitative analysis).

Lastly, in terms of data analysis, a mixed-methods approach was assumed, combining quantitative econometric panel data analysis with a fuzzy-set qualitative comparative analysis that benefited from recent advancements in panel data set-theoretic research (Oana and Schneider, 2018). Molina-Azorin et al. (2017) noted an increase in the integrated use of quantitative and qualitative methods, such as Muñoz-Pascual et al. (2021) and Cruz-Ros et al. (2021). We aim to highlight the usefulness of using both qualitative and quantitative methodologies to show effects that cannot be captured using only one methodology. This study examines the effects of SDG9 variables on innovation capacity, as depicted in Fig. 1.

4. Variables, data, and method

4.1. Sample description

The purpose of this study is to determine the factors of competitiveness in the Eurozone. Based on the variables that make up SDG9 such as scientific and technical journal articles (per 1000 population), expenditure on research and development, number of researchers (per 1000 employed population), and triadic patent families (per million population) will help to find the paths for competitiveness in the countries within the sample (Table 1). Data were collected from the World Bank, OECD, and ITU/United Nations databases in Eurozone countries for the period 2010–2019. The analysis fell on these countries because they are under the rules in terms of monetary policy, and therefore, the comparison is more reliable.

Of the 19 countries making up the Eurozone, due to missing values, the final sample comprises of 17 countries, as no figures are available for the number of researchers in Cyprus and Malta (Table 2).

4.2. Data

Table 2 shows the descriptive statistics of the variable outcome (GCI) and the dependent variables that are part of the SDG 9. The GCI presents an average of 4.4 on a scale that ranges from 1 to 7, with the highest GCI presented as 5.75 in Germany in 2009, and the lowest GCI was found in Greece in 2011. The descriptive statistics of independent variables, articles and Rdex, is shown in the table. In the case of articles, the range presented in the sample shows a fluctuation between 395 in Luxembourg in 2009, and 108,473 in Germany in 2014. In the case of Rdex, Latvia presented a minimum of 0.44 in 2016 and a maximum in 2009.

The Pearson correlation matrix (Table 4) displays the results of the analysis of the relationship between GCI and other independent variables. The GCI was positively correlated with all independent variables. The correlations show that statistically significant values provide evidence that there may be a relationship between the variables. Multicollinearity problems may occur if there are relationships between the variables. To avoid this problem, we performed a VIF test with the results lower than 10 (Table 3), as suggested by Meng et al. (2017). Given the above, it is guaranteed that the relationships are stable and can be analyzed through linear regression in panel data, given the stability of the correlations.

5. Econometric panel data analysis

To see how the variables that make up SDG 9 explain innovation capacity, a regression was used to determine the explanatory power of

Table 1
Description of variables.

	Name	Acronym in the paper	Description
Dependent variable	Global Competitiveness Indicator	*GCI*	Capacity for innovation. This variable ranges on scale 1 to 7, in which 1 refers to the lowest value and 7 to the highest; a high value represents good performance in the ranking
Independent variables	Population using the internet (%)	*intuse*	The percentage of the population who used the Internet from any location in the last three months. Access could be via a fixed or mobile network.
	Scientific and technical journal articles (per 1000 population)	*articles*	The number of scientific and technical journal articles published, that are covered by the Science Citation Index (SCI) or the Social Sciences Citation Index (SSCI). Articles are counted and assigned to a country based on the institutional address(es) listed in the article.
	Expenditure on research and development (% of GDP)	*rdex*	Gross domestic expenditure on scientific research and experimental development (R&D) is expressed as a percentage of Gross Domestic Product (GDP). We assumed zero R&D expenditure for low-income countries that do not report any data.
	Researchers (per 1000 employed population)	*rdres*	The number of researchers per thousand employed people. Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods, and systems, as well as in the management of the projects concerned.
	Triadic patent families filed (per million population)	*patents*	A triadic patent family is defined as a set of patents registered in various countries (i.e. patent offices) to protect the same invention. Triadic patent families are a set of patents filed at three of these major patent offices: the European Patent Office (EPO), the Japan Patent Office (JPO), and the United States Patent and Trademark Office (USPTO). The number of triadic patent families is "nowcast" for timeliness.

The data were retrieved from the World Bank (GCI, sdg9_articles, sdg9_rdex), OECD (sdg9_rdres, sdg9_patents), and ITU/United Nations (sdg9_intuse) databases.
Source: Authors.

these variables in that outcome. The analysis was conducted using the STATA software. The results in Table 5 show that the regression model is significant. We estimated the model using OLS and OLS-FE, reaching an overall R^2 between 76,9 % and 83.7 %, respectively, indicating that more than three-quarters of the variability is explained by the independent variables that are presented in the model. In terms of the contribution of the variables that make up SDG9 to explain competitiveness, almost all the variables are statistically significant, with the exception of the variable patents.

As shown in Table 5, all independent variables presented a positive relationship with competitiveness. Contrary to the literature, the intensity and significance of the relationship are very different from variable to variable. The sdg9_rdex variable stands out from all others, presenting not only a strong but also statistically significant relationship intensity. In economic terms, each unit increase in R&D expenditures induces an average increase between 0.36 and 0.4 in GCI, for OLS and OLS-FE estimation method, respectively.

The results are similar, which can be interpreted as countries' R&D per se affecting competitiveness.

6. Panel data fuzzy-set qualitative comparative analysis

The fuzzy-set Qualitative Comparative Analysis (fsQCA), in opposition to the correlation methods, allows identifying the effect in a variable and its direction and the magnitude and their possible combinations with other variables (Ragin, 2008b). In addition, the fsQCA method allows for the possibility of different combinations to generate the same result, leading to different configurations (Ganter and Hecker, 2014; Rodrigues et al., 2020). According to Fiss (2011) and Furnari et al. (2021), the major advantages of this methodology are its equifinality, multicausality, and asymmetry.

This section presents a descriptive analysis of the sample and labels the calibration process for variables. Subsequently, the necessary and sufficient conditions of the configurations to obtain the innovation capacity in our data are detailed.

6.1. Data calibration

For data calibration, we transformed the variables into values between 0 and 1, that is, fuzzy scores (Fiss, 2011). The degree of membership is reflected in the fuzzy scores (Woodside and Zhang, 2013). Following Ragin (2008a), Pappas and Woodside (2021) chose thresholds of 95 %, 50 %, and 5 %, where 95 % represents all membership cases, 50 % represents cases of ambiguity, and 5 % denotes cases of absence. The calibration results are listed in Table 2.

6.2. Necessary and sufficient conditions analysis

After the calibration process is finished, the next step in the FsQCA methodology is to analyze the necessary conditions to achieve the outcome in the case of GCI. To determine the necessary conditions, it is required that each variable has the prefix "fs" before the name of the variable. Subsequently, it was necessary to test the presence and absence (~ indicates absence) of each of the independent variables of the model

Table 3
Results of VIF test.

Variable	VIF	1/VIF
Patents	5.280	0.189
Articles	4.610	0.217
rdex	3.510	0.285
rdres	2.910	0.344
Intuse	1.370	3.540
Mean VIF	3.540	

Table 4
Pearson correlation matrix.

Variable	1	2	3	4	5	6
GCI	1					
Intuse	0.692***	1				
Articles	0.404***	0.0247	1			
rdex	0.751***	0.419***	0.394***	1		
rdres	0.599***	0.421***	−0.00760	0.750***	1	
Patents	0.520***	0.193***	0.868***	0.490***	0.490	1

Note: This table presents the Pearson's correlations of the variables used in this study.
*** $p < 0.01$.

Table 5
Regression OLS GCI, full sample.

Variables	(1)	(2)
	OLS	OLS-FE
	GCI	GCI
sdg9_intuse	0.0364***	0.0324***
	(0.00325)	(0.00333)
sdg9_articles	5.01E-06*	4.04e-06*
	(2.59E-06)	(2.41e-06)
sdg9_rdex	0.34373***	0.409***
	(0.080869)	(0.0712)
sdg9_rdres	0.0446365**	0.0342*
	(0.0207161)	(0.0179)
sdg9_patents	0.000731	8.30e-05
	(0.0000625)	(6.05e-05)
Year dummies	No	Yes
Constant	0.5087566**	1.024***
	(0.2436002)	(0.231)
Observations	187	187
R-squared	0.769	0.837
Number of countries	17	17

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 2
Descriptive (summary) statistics and calibration.

Variable	Mean	Std. Dev.	Minimum	Maximum	N	Cases missing	Calibration
GCI	4.476577	0.8491445	2.5365	5.95	187	0	(5.65;4.6;3)[a]
Intuse	77.8675	11.31211	42.4	98.137	187	0	(93;80;55)[a]
Articles	24,163.47	29,899.02	395.89	108,473	187	0	(100,000;11,200;820)[a]
Rdex	1.714011	0.797277	0.44	3.73	187	0	(3.1;1.45;0.625)[a]
Researchers	8.349091	2.701825	3.56	16.61	187	0	(14.5;8;4.1)[a]
Patents	617.5379	1201.822	0.2	5554.1	187	0	(4600;100;3)[a]

[a] Cuts: 95 %; 50 % and 5 %.

Table 6
Results of necessary conditions.

Outcome variable: fsGCI			Outcome variable: ~fsGCI		
Conditions tested:			Conditions tested:		
	Consistency	Coverage		Consistency	Coverage
fsintuse	0.824441	0.806094	fsintuse	0.493237	0.470820
~fsintuse	0.458776	0.481140	~fsintuse	0.796861	0.815882
fs_articles	0.641332	0.748174	fs_articles	0.468166	0.0533202
~fsg_articles	0.599863	0.536032	~fsg_articles	0.778890	0.679497
fs_rdex	0.844066	0.82652	fs_rdex	0.500852	0.477723
~fs_rdex	0.465428	0.488518	~fs_rdex	0.816163	0.836330
fs_rdes	0.769573	0.814437	fs_rdes	0.498292	0.514831
~fs_rdes	0.541557	0.525089	~fs_rdes	0.820398	0.776555
fs_patents	0.637949	0.889671	fs_patents	0.334574	0.455522
~fs_patents	0.609576	0.484092	~fs_patents	0.918965	0.712479

Note: ~ = indicates absence.

Table 7
Results of intermediate solutions (outcome of informality and absence of GCI).

	fsGCI				~fsGCI			
Frequency cutoff	72				97			
Consistency cutoff	0.89824				0.847709			
Variables	1	2	3	4	1	2	3	4
fs_intuse			●	●	O	O		O
fs_articles	●		O	●		O	O	●
fs_rdex	●	●	●		O		O	O
fs_rdes		●		○			O	O
fs_patents	●	●	O	●	O	O	O	
Consistency	0.954038	0.960405	0.907455	0.935008	0.964628	0.912097	0.862311	0.9622
Raw coverage	0.589327	0.520993	0.429599	0.299558	0.627278	0.614585	0.60283	0.3663019
Unique coverage	0.0758121	0.0117926	0.102965	0.00322032	0.0482618	0.0959092	0.112184	0.0348888
Overall solution consistency	0.901804				0.870261			
Overall solution coverage	0.720124				0.843946			

Note: ● and ○ represent the presence and absence of a condition, respectively. Large circles indicate core conditions, and small circles indicate peripheral conditions. Blank spaces indicate "does not contribute to the configuration".

presented. A condition is considered "necessary" if it exceeds 0.9 and "almost always necessary" if it exceeds 0.8. (Schneider et al., 2010; Fiss, 2011). Table 6 illustrates that there is one necessary condition (~fs_patents) in the case of outcome absence of a GCI.

Thus, the next section analyzes the configurations of variables that lead to higher values of GCI and its absence in the Eurozone countries of the sample between 2009 and 2019.

6.3. Causal configurations for GCI and absence of GCI

The main goal of this study is to identify "recipes" for a higher GCI in Eurozone countries and the "recipes" for the absence of a high GCI. We can advance to the next step, which runs the fuzzy-set algorithm and generates the truth table. Preceding the analysis of the necessary conditions was that of the sufficient conditions. In this case, sufficient conditions and causal configurations can provide finding paths to GCI and the absence of GCI. Considering an inclusion cutoff of 0.8, based on the recommendations of Schneider and Wagemann (2012) and Cruz-Ros et al. (2021), both individual consistency and coverage, as well as overall consistency and coverage, were calculated. The solution consistencies and coverage for the GCI are presented in Table 7 (each column represents a different path). Based on the truth table, a Proportional Reduction Inconsistency (PRI) higher than 0.5 were also scrutinized to find the outcome conditions required to avoid "false positives". The choice of this value is justified by configurations with PRI scores below 0.5 indicating a significant inconsistency (Greckhamer et al., 2018). The same procedure was performed in the absence of GCI. The software presents three different results: the complex, the parsimonious, and the intermediate solution. Based on the intermediate solution provided by the software, it can be inferred that these four solutions allow a higher GCI to be achieved.

The results show several highlights: a clear predominance of high values of the independent variables and "core" conditions. Among the independent variables, the fs_rdex and fs_patents variables present high values in almost all configurations; the difference between them is the fact that the behavior is indifferent in the case of fsrdex and absent in the case of fs_patents variable. The fs_intuse and fs_articles variables in half of the configurations present high values and in the remaining ones, the behavior is different. The behavior found in the configurations of the fs_rdres variable is antagonistic because it presents high values in one solution but presents low values in another. However, in half of the configurations, the behavior to explain the outcome is indifferent.

In the absence of GCI, we found four solutions. It is noteworthy that the predominance of low values in almost all variables is to highlight the variables fs_intuse, fs_rdex, and fs_patents that in three of the four configurations found low values. Another aspect that stands out from the output is the fact that to reach the absence of innovative capacity, there must be high values of the variable fs_articles in one solution.

These findings reflect the described assumptions of fsQCA (Fiss, 2011): (1) Equifinality, where more than one configuration of conditions leads to fsGCI and ~fsGCI; (2) alternative causal configurations can produce the same outcome (different paths were found to achieve fsCGI and ~fsGCI); and (3) asymmetry, where the conditions of the outcome differ from those of its absence.

7. Discussion

When comparing both the panel data results and the fuzzy-set analysis, it is possible to verify that the variables measuring the population using the Internet and the expenditure on R&D exhibit a positive and statistically significant relationship at 1 % with the competitiveness index (Table 5). They are also presented as core conditions in some of the combinations for a higher competitiveness index. Hence, the variable intuse is in two of the four combinations (high values) and rdex is in three of the four combinations (Table 7). This finding is in line with Salman et al. (2020). However, it is important to note that for some combinations, Internet use is irrelevant to the solution (not in a combination), suggesting that countries can also achieve high levels of GCI if the other variables have high values, such as a high number of patents or a high number of researchers.

By comparing both outputs, it is possible to establish that although the variable patents in the panel data analysis do not present a statistically significant association with the competitiveness index, in the fuzzy set analysis, the variable patents are a necessary condition for the outcome variable. This can also be verified by the fact that the variable is present in all combinations (with either high or low values) as a core condition. These results are in line with Trappey et al. (2012), as companies and, consequently, countries that fail to protect their innovations can end up losing competitiveness.

Finally, the number of articles and researchers also present positive and statistically significant relationships at the 10 % level with the competitiveness index, but the causal combinations exhibit both positive and negative relations. In other words, combination 3, with a low number of articles combined with the remaining variables, can also lead to high CGI values. With regard to the number of researchers, adding to the fact that in not a peripheral condition (small circle) and a core condition, in combination 4, low values of this variable together with the remaining variables can also lead to high CGI scores. This finding suggests that both variables should be on the agenda of policymakers; however, they should be carefully analyzed, and policies aimed at improving these variables should be combined with policies to improve complementary variables.

8. Conclusions, implications, and further research

The panel data test shows a meaningful and strong relationship between CGI and sdg9_rdex. The dependencies of GCI on the other variables, although statistically significant, did not show considerable intensity. The exception is the variable patents, which shows no statistical significance. A quantitative study showed the centrality of sdg9_rdex, which was confirmed by the QCA study; the variable was present in three of the four solutions.

However, a qualitative study (QCA) provides another perspective on how the independent variables are organized to enhance competitiveness. The study shows four different configurations associated with high competitiveness. The variables sdg9_rdex and sdg9_patents were present in three configurations (not coincident), and the variables sdg9_intuse and sdg9_articles were present in two configurations with high values. Only the variable sdg9_rdres influences competitiveness in a more discrete manner (present only and in a non-core manner).

The QCA results thus validate not only the literature, where we find arguments that these five variables all influence competitiveness, contrary to what the econometric study indicated, highlighting the advantages of using qualitative and quantitative methods to describe and solve socioeconomic issues.

The design and evaluation of public policies for science and technology cannot, therefore, fail to consider the five variables in tandem.

This fact is corroborated by an analysis of the fsGCI variable. Again, these four configurations are associated with poor competitive performance (absence). All five variables considered were present in at least two configurations (sdg9_intuse, sdg9_rdex, and sdg9_patents, with an absence condition in three configurations, and sdg9_articles and sdg9_rdres, with an absence condition in two configurations). Such a strong presence of variables shows that when there is no good performance on a relatively small number of variables, whatever they may be, the country's ability to nevertheless be very competitive through performance excellence on some of the other variables becomes very unlikely.

Thus, the scientific and technological system should be seen as a whole, and efforts should be directed toward developing it in an articulated manner in its various dimensions. For example, increasing the number of scientists through training processes abroad - has a limited impact on competitiveness if it is not complemented by others in the other dimensions - for example, encouraging the publication of articles or fostering industrial property.

The results of the are limited due to the variables used and the countries considered. Further studies of a confirmatory nature that consider other variables and another set of countries are desirable.

Analyze other countries such as the UK, USA, or China to check if the independent variables present the same behavior or if the culture of these countries can change their competitiveness. Try to capture other factors in SDG9 that help explain the outcome (competitiveness). More research can be conducted to analyze the components of SDG8 (decent work and economic growth) to measure their impact on competitiveness.

Author statement

None.

Data availability

Data will be made available on request.

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