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International collaboration towards innovation management: a network perspective and the Global Innovation Index

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Abstract

This article aims to fill an existing knowledge gap within the literature: the characteristics of networks of publication on innovation management research and its relationship with country's innovativeness. The study is grounded in the theory that the creation of knowledge and collaboration within networks play a pivotal role in improving a nation's innovation capacity. It presents and describes the characteristics of co-authorship networks of scientific publications among authors from different countries. The published articles were extracted from the Scopus and Web of Science databases, considering a period of 12 years. Following the identification of pivotal countries, the research proceeded to investigate whether their positioning within the network has an impact on their innovation capabilities. To underpin this analysis, data from the Global Innovation Index ranking were employed. Among the six countries demonstrating noteworthy centrality metrics throughout the entire period, Germany, the United States, and the United Kingdom are also categorized as innovators according to the Global Innovation Index. The overlap observed suggests a relationship between countries maintaining consolidated and resilient innovation networks and positive performance in terms of innovation. However, it should be noted that innovation is influenced by a range of factors, including strategies and policies on international collaboration.

Keywords: Innovation management, Co-authorship networks, Scientific collaboration, Global Innovation Index

Introduction

Innovation has become an increasingly powerful representation of economic growth, and depends not only on institutional and cultural factors, but also on technology, values, and investments. The quality of the institutional environment and interactions between institutions positively affect innovation (Mercan & Göktas, 2011).

Involvement in collaborative networks can be an important enabler of innovation for science in the public sector and technological organizations (Fonseca et al., 2017). A key resource in a regional innovation system is the network through which knowledge can be transferred between organizations in the region.

Universities and science and technology institutions (S&Ts) are important contributors to the provisions of new scientific and technological knowledge (Lundvall, 2010). Combined with the fact that research is important to the prestige of universities and individual researchers, the pressure of funding has spurred academia towards a greater collaboration with the industry.

The publication of R&D results makes scientific literature an established source for extensive information on activities of this type. Several approaches have been developed to use this information to analyze the structure of scientific fields. Collaborations create a system of communication between researchers who have a common goal, and although it is difficult to observe the communication itself, it is possible to assess the outcome of these collaborations through the shared authorship of a research article (Newman, 2001a).

Innovation management has become an important area of academic interest as scientists operating in complex social worlds form various kinds of knowledge networks such as citation networks, co-author networks, keyword networks.

Creating competencies in the field of innovation management is essential for several reasons, as these skills empower professionals and organizations to successfully lead innovation processes. Developing specific competencies in innovation management allows companies to extract the maximum potential from their innovative efforts. Skilled professionals can identify opportunities, evaluate ideas, develop solutions, and implement new products, services, or processes more effectively.

Innovation management is a strategic investment that can lay the foundation for sustainable wealth generation over time, helping companies thrive and stand out in an ever-changing market. Beyond being a channel for wealth generation, innovation management encompasses a wide range of knowledge areas, as it involves a multidisciplinary approach to promoting and managing innovation processes within an organization. Innovation is not solely about technology; it also involves strategy, organizational culture, human resources, marketing, finance, and much more.

Thus, even though existing research has provided a solid understanding of the benefits of diversity that encompasses innovation processes and the relationship between network structures and their results, this study holds an innovative quality, in that it illustrates the academic engagement that provides the creation and mobility of innovation management knowledge generated by universities in the field of innovation management.

The purpose is then to explore the dynamics of knowledge creation on this subject from an international-level perspective. The discussion presented on the characteristics of academic publication networks for "innovation management" prove interesting not only to explore the dynamics of a network, not yet addressed by previous studies, but it also has practical implications for results that can be replicated at the regional level.

To characterize these relationships, this article identifies innovation networks based on data from publications pertaining to innovation management. Furthermore, the present study aims to analyze how the outcomes of academic research, viewed through the lens of knowledge generation and collaborative networking, can play a pivotal role in enhancing

the national innovation capacity. This will be achieved through an analysis connected to the Global Innovation Index (GII), which gauges innovation on a global scale.

Although the outcome of innovation is generally not measurable, it is acceptable to consider it affected by the structure of the network, the strength of connections and the exchange of knowledge (Choi et al., 2010). It is important to understand the results related to each country's innovation ranking within the global networks by considering that agents make use of advantages due to their positions within the networks analyzed, of which, at least indirectly, reveals the dissemination of knowledge in the scope of innovation management.

Global innovation indices play a significant role in understanding and evaluating the innovation capacity of countries and economies on a global scale. For over a decade, the Global Innovation Index (GII) has been fostering national innovation strategies and international innovation discussions through three primary avenues. Initially, the GII assumes a crucial role in firmly establishing innovation as a priority for countries, especially those in low and middle-income brackets. Secondly, it enables countries to assess the relative performance of their national innovation systems, scrutinizing strengths and weaknesses in innovation. These insights subsequently guide innovation policies and actions. Thirdly, the GII serves as a robust incentive for countries to gather appropriate innovation metrics (The Global Innovation Index [GII], 2019).

Considering that the justification has already been presented, the object of study is to answer the question: "Do countries that stand out within academic networks of scientific publications on innovation also are linked to a greater innovative potential, when considering their position in the Global Innovation Index ranking?".

A comparative analysis of countries excelling in centrality indices (degree and intermediation) within the studied networks, along with their placements in the GII, provided valuable insights into the connection between scientific collaboration and the observed levels of innovation in these nations.

The countries that stand out for their relevance both in co-authorship networks concerning innovation management publications and for their high innovation character according to the GII are Germany, the United States, Finland, the Netherlands, the United Kingdom, and Switzerland. This overlap may suggest that these countries possess well-connected and robust innovation networks, contributing to their positive innovation performance. Prominence in a co-authorship network can suggest that a country is actively engaged in research production and international collaboration, both of which are important elements for innovation. However, innovation also depends on other factors such as investment in research and development, the business environment, education, innovation policies, and so forth.

This provides a reference for policymakers to assess their countries' innovation performance and identify areas requiring improvement, empowering governments and institutions to make informed decisions regarding resource allocation, policy development, and strategies to promote innovation.

Literature review

A concise overview of the historical precedence of innovation management and co-authorship networks is provided in the following sections. It is important to note that this overview is not exhaustive, given the extensive literature available on these subjects.

Finally, the existing literature on studies examining social networks and innovation is presented.

Innovation management and its environment

Although there are many questions regarding innovation, the traditional idea that innovation is based on research and development, and on the interaction between companies and other agents has been replaced by the current social network theory, where knowledge plays a crucial role in promoting innovation. Knowledge about innovation can be used to modify innovation, processes, and environments to generate innovation (Hashimoto et al., 2012; Hidalgo & Albors, 2008).

Tidd (2001), after an extensive and diversified research of innovation management literature, suggests that the complexity and uncertainty of the environment can affect the degree, type, organization, and management of innovation, and the greater the fit between these factors, or the more coherent the configuration, the better the performance. Successful resource coordination entails more than just designing inter-organizational mechanisms; it also involves the targeted selection of ideas, knowledge, and collaborators. Innovation management tools implementation not only facilitates the company's capacity to introduce appropriate new technologies, but also contributes to the necessary organizational changes to foster continuous innovation (Igartua et al., 2010).

Innovation management is a necessary framework for creating knowledge innovation, one of the key sources of sustainable competitive advantage (Lee, 2016). Thus, understanding how this theme evolves is essential to understand how knowledge is created and shared, enabling the identification of the most relevant clusters at a global level.

The technological capacity of an innovation system stems from the existence of interactive learning (Cooke et al., 1997).

Collaboration between policymakers, businesses and academia is also essential not only to disseminate academic trends and apply the results of academic research to policy, but also to stimulate academic research that focuses on topics pertinent to policymakers and industry (Hashimoto et al., 2012). Increasingly, the structure of collaborative networks in science and technology, including governmental support in strategic areas of development for the country, represents a strategy to promote a greater integration of innovation agents, building links to substantially increase the transfer and application of knowledge, investment in R&D and attracting highly skilled researchers to companies (Varrichio et al., 2012).

Thus, understanding how this theme evolves is essential to understand how knowledge is created and shared, enabling the identification of the most relevant clusters at a global level. To advance innovation management research, countries and institutions should strategically position themselves within networks to access vital resources. Barrichello et al. (2020) highlight that top innovative countries prioritize quality research institutions and patent applications, key drivers for development. Network analysis offers insights into research and knowledge flow between actors. As Wagner and Leydesdorff (2005) emphasize, free knowledge flow within research systems fosters growth and ensures local knowledge availability and national policies can either facilitate or hinder these crucial knowledge flows.

The spread of new knowledge is likely to be more extensive when considering the well-established national and international networks of scientists in these countries. This is attributed to their central role in the international research network and the substantial number of countries with which they engage in collaborative publications (Vieira et al., 2022). At the core of the field of innovation management lies an ecosystem of collaboration, where researchers forge connections through various knowledge networks, such as citation and co-authorship networks (Newman, 2001a).

Co-authorship networks

Complex networks have been extensively studied due to their effectiveness in describing a wide array of systems across various disciplines (Molontay & Nagy, 2021). In recent decades, there has been a considerable increase in interest in the concept of networks and the associated methodology of social network analysis (SNA), when considering innovation research (Cantner et al., 2010). Social network theory has been widely employed, as it provides researchers with the opportunity to explore the individual impact of a node while also elucidating how social relationships among actors can be quantified (Wasserman & Galaskiewicz, 1994).

Fonseca et al. (2016) indicates that research has suggested leveraging social network analysis (SNA) to: (1) aid in assessing cross-disciplinary research programs; (2) facilitate strategic public policy planning; and (3) enhance innovation management within public health systems. Furthermore, SNA has been utilized for organizational competitive intelligence and managing communication networks within the health innovation system.

Co-authorship networks are a type of social network and have been used to study the structure of scientific interactions and the status of individual researchers (Newman, 2004; Quattrociocchi et al., 2012). In the case of a co-authorship network, the nodes represent the authors, and the links represent the articles produced through partnerships (Slone, 1996).

A co-authorship network implies stronger membership than a network of scientific citations (Hummon & Dereian, 1989; Liu et al., 2005), given that citations can occur without the cited author knowing the authors citing their publications (Amancio et al., 2012). These networks are used to answer a wide variety of questions about the patterns of collaboration, such the typical distance between scientists within the network and how the patterns of collaboration vary across subjects and through time (Newman, 2004). In the case of the co-authorship network, the networks are considered undirected and weighted, given that the co-authorship relationship is undirected, and its weight is based on the number of articles published collaboratively (Muthusamy & White, 2005).

Researchers' network properties are found to be significantly correlated with their scholarly performance. Those who engage with a greater number of co-authors tend to achieve better results in their academic endeavors. Additionally, researchers with efficient co-authorship networks demonstrate enhanced scholarly outcomes. These findings highlight the importance of network characteristics in shaping academic success and underscore the value of collaborative endeavors in academic research (Abbasi et al., 2012).

A significant finding from the research conducted by Barabási et al. (2002) is the confirmation of the existence of the preferential attachment phenomenon. This phenomenon is a characteristic feature of scale-free networks, wherein the selection of new co-authorship partners is influenced by a preference to collaborate with authors who already have a well-established history of collaborations. Strong ties within networks are demonstrably linked to both collaborative efforts among partners and the crucial task of enabling knowledge circulation. This facilitates members' acquisition of valuable insights beyond their established boundaries (Cowan et al., 2007).

Existing literature

While numerous studies investigate social networks and innovation, they largely cluster into three categories: (1) those narrowly scrutinizing co-authorship patterns within patent data; (2) those adopting a broader lens on scientific networks; and (3) those focusing on their influence within specific regions or countries.

Iino et al. (2021) investigated the influence of firms' research collaboration on innovation quality through the analysis of global co-patenting data. Dolfsma and Leydesdorff (2008) employed data on patents networks granted by the World Intellectual Property Organization (WIPO), a UN organization, to delineate national innovation systems. Vasconcellos and Morel (2012) studied policy formulation and innovation oversight through the examination of patent data and collaborative network structures in Brazil. In contrast, Fagerberg and Srholec (2008) emphasize that measuring a nation's innovation system or capability solely through quantifying patents may be insufficient, particularly for countries below the technological frontier, especially those in developmental stages.

Luukkonen et al. (1992) analyzed international scientific collaboration, investigating co-authorship patterns, country-to-country rates, and collaboration networks across various scientific fields. Ribeiro et al. (2018) explore the extent and stability of global scientific collaboration, delving into network properties and long-term behavior with implications for the global innovation system. Newman (2001a) examines the structure of scientific collaboration networks in biomedical research, physics, and computer science. Newman (2004) identifies patterns in scientific collaboration using data from biology, physics, and mathematics databases. Isfandyari-Moghaddam et al. (2023) examine co-authorship networks among the top 60 countries with the highest scientific publication volumes globally and identifies collaboration patterns in highly cited papers from these countries, encompassing data from all scientific publications.

Cantner et al. (2010) delved into the regional innovation system approach through three case studies in Germany, concentrating on the regional networks of innovators. Their analysis focused on how the size and homogeneity of the knowledge base within each network influence knowledge flow and collaboration. Fonseca et al. (2017) investigated the networks of two Brazilian public health institutions, utilizing indicators for both scientific collaborations and technological partnerships. Ebadi and Schiffauerova (2015) conducted a study analyzing co-authorship networks of Canadian researchers in natural sciences and engineering over a span of 12 years.

This study fills a gap by analyzing how international networks impact innovation outcomes, thereby advancing our understanding of the global innovation landscape with a broader and more holistic perspective. Innovation management is crucial for

transforming knowledge into innovative practices, with exceling in relevant academic networks suggesting a strong knowledge base and expertise in applying these strategies. Excellence in publication networks can reflect a cohesive and efficient national system, where knowledge exchange and collaboration between diverse entities foster innovation through robust networks.

To evaluate a country's innovativeness, the common practice involves the use of innovation indexes. These indexes provide a systematic and quantifiable method for measuring and comparing innovation efforts and outcomes across nations, offering a global perspective to identify innovation leaders and areas for enhancement. Mercan and Göktas (2011) leverage the Global Innovation Index (GII) dataset to investigate cluster development, university–industry collaboration, and innovation culture and their impacts on innovation creation. In this study, the authors also opted for the GII, a quantitative measure of innovative performance distinguished by its international collaboration, which ensures a diverse perspective for a comprehensive understanding of innovation in various contexts. The GII data's variables, particularly in technology, are continuously updated and developed, with ongoing incorporation of new variables to enhance the index (Pençe et al., 2019).

Methodology

The key points that this research answers include the following: (i) what is the structure of co-authorship networks for innovation management? (ii) What are the dynamics of co-authorship networks across countries? (iii) What are the countries that hold prominent positions in the networks? and (iv) Are these the same countries that excel in the Global Innovation Index rankings?

Academic publication networks serve as the main indicator for assessing a country's innovative capacity due to the presence of publication years and universities' comprehensive publication data. This choice allows for temporal segmentation and in-depth network analysis. While alternative approaches exist, this perspective provides a focused yet expansive exploration, enhancing the study's depth and relevance.

The analysis of scientific research was conducted through social network analysis metrics, aiming to understand the relationship between network connectivity and the quality of the innovation ideas created, considering the premise that quality is closely related to the innovative character of the country. The characteristics of networks were discovered by calculating different metrics, such as global network metrics and centrality metrics, including degree centrality and betweenness centrality. The visualization method was also used to support the analyses.

Data collection and processing

An initial search using the keyword "innovation management" in title, abstract, and keyword fields yielded 2422 scientific publications from the Web of Science (WoS) database. A similar search in the Scopus database produced 2097 publications. Only articles and proceeding papers were considered for analysis to ensure material quality. The combined results, totaling 4519 publications, were reviewed by authors. It is important to note that data for this analysis were collected in August 2019, providing a partial view of that year but not affecting the structural analysis of networks.

The selected publications' data underwent processing using VantagePoint (Search Technology Inc.) software, tailored for the WoS and Scopus databases. Duplicates were eliminated and, subsequently, a comprehensive analysis was performed to standardize authors' names, affiliations, and respective countries. The processed data, comprising a matrix of nodes and links, was stored for analysis using Gephi software, an open-source tool for graph analysis, that facilitated the generation of co-authorship networks and provided essential metrics.

Nations of heightened prominence within the constructed networks were discerned through the utilization of node centrality measures. This identification process was systematically executed by applying a selection criterion up to the fifth highest value for each measure, demonstrating a meticulous approach in the analysis of individual contributions to the network. To ascertain the most pertinent countries in the GII, the authors chose those positioned within the top 10 rankings, thereby ensuring methodological consistency, given the systematic examination of this segment in the GII's annual reports.

Results and discussion

It is important to select a period to obtain the most realistic scenario for evaluating the dynamics of interactions between researchers. That is, if the time periods were too small, most researchers would have no connections—in contrast, if the time periods were too large, a high percentage of researchers would have some connection (Mugnaini et al., 2014). In this article, four three-year time windows were selected to evaluate the dynamics of networks over time, considering the period of 2008 to 2019 for the analysis, which represents 3712 articles, and around 82 percent of the initial database. Figure 1 shows the evolution of the number of publications per year.

The results extracted from the analysis are presented in this section. The presentation is structured according to Quattrociocchi et al. (2012) and Fonseca et al. (2017), to provide the reader with a top-down perspective on the processes that characterize the evolution of the scientific network. First, a synthesis of the global network dynamics and the patterns of community formation is provided; next, the micro-levels of interaction in the network are presented, explaining the evolution of the nodes' connections.

Global graph metrics describe the characteristics of a social network as a whole. This article, for the network-level metrics, focused on the number of agents (nodes) and links, average degree, average path length, network modularity, number of existing

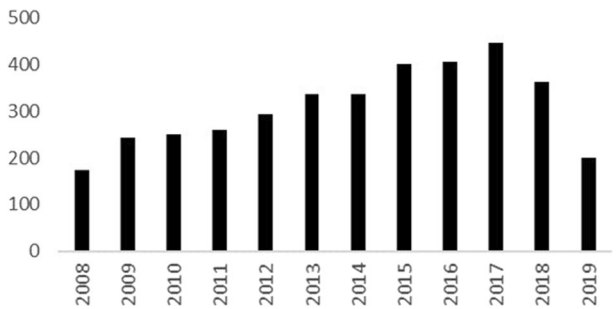

Fig. 1 Number of scientific articles published per year, during 2008–2019*, about "innovation management"

communities, and density. Node properties relate to the analysis of individual properties of network agents. An agent´s position is generally expressed in terms of its centrality, that is, the measure of how central the agent is within the network. Here, for the individual level of metrics, degree of centrality and betweenness centrality were considered.

Global scope metrics: building scientific knowledge

This article's database comprised 106 countries, and the number of countries that published each year for the specified period is shown in Fig. 2. There is a tendency in the increase of countries involved in the research area, which may indicate that collaborative scientific production is more widespread within a global knowledge system (Higgins & Ribeiro, 2018). China, Germany, United States and United Kingdom are the leaders in scientific production when considering the 12-year period analyzed, representing 37.87 percent of the total produced.

The connections are explored at the nation-to-nation level with the assumption that nations represent an underlying political and cultural structure of scientific support (Girvan & Newman, 2004). Table 1 presents the evolution of the participation of countries and their connections.

It is worth mentioning that, of the networks presented here, countries that did not publish with authors from other countries over the three-year period considered were excluded. Namely, there were 16 countries between 2018 and 2010, 26 countries between 2011 and 2013, 19 between 2014 and 2016, and 16 between 2017 and 2019. Such a number is high when considering the total number of countries involved in each triennium analyzed, representing 26.6%, 35.1%, 24.0% and 18.8 %, respectively.

The number of countries with authors in the analyzed networks grew by approximately 9% in the first three years, followed by a notable 25% increase in the second triennium and 15% in the third, signaling increased global engagement in this research area. Links between countries, representing author collaborations across borders, also rose over time, with a 10% increase between the first two triennia, a significant 74% surge in

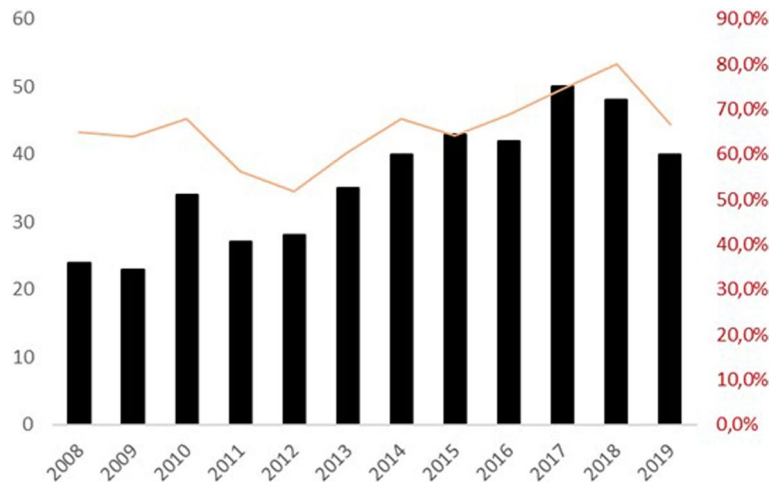

Fig. 2 Number of countries per year who published through co-authorship, during 2008–2019, on "innovation management". The bar graph represents the absolute number of countries, and the line graph represents the total percentage of countries who published within that specific year

Table 1 Evolution of co-authorship networks for publications between countries per triennium, during 2008–2019*, on "innovation management" in the Web of Science and Scopus databases, after removing duplicates

Period	Titles	Titles (percent)	Nodes	Nodes (percent)	Links	Links (percent)
2008–10	665	–	44	–	109	–
2011–13	890	133.8	48	109.1	120	110.1
2014–16	1145	128.7	60	125.0	209	174.2
2017–19*	1010	88.2	69	115.0	224	107.2

*Publications from up until August 2019 were considered

the third, and a slight 7% rise in the final period analyzed. This trend suggests a growing international interest in seeking knowledge about innovation management. It is worth noting that the data for 2019 might not be fully compiled, potentially indicating even more substantial growth.

The co-authorship networks between countries were reconstructed to portray the structure and collaboration in publications, as shown in Fig. 3. The methodology was used according to the study made by Fonseca et al. (2017), who analyzed social network indicators for science and technology organizations from the Brazilian public health sector. To complement the analysis, Table 2 presents the main network analysis metrics from a global point of view.

The average degree signifies the average number of connections nodes in a given network possess. Notably, there is a slight increase in the average degree when comparing the first three triennia, followed by a minor decrease in the final period. This suggests a trend of heightened collaboration within the network from 2008 to 2016.

The average path length, representing the average shortest path between any two nodes in a network, has remained stable and short despite the considerable increase in countries and collaborations. In real networks, a shorter average path facilitates rapid information transfer, reduces costs (Albert & Barabási, 2002), and reflects a small-world concept where everyone is connected. Small-world networks, like the one observed, enhance the dissemination of ideas across clusters and foster the production of new knowledge (Ebadi & Schiffauerova, 2015).

Density, a key concept for network structure analysis, indicates the general level of connections between nodes. Throughout the analyzed period, density values show that around 10% of all possible connections are effectively used within the networks each year, indicating a relatively low degree of interaction considering all available countries.

Community structure, involving the division of a network into groups with dense internal connections and sparse external connections, was assessed using modularity. Modularity metrics revealed stability in the first two triennia, with a slight reduction in subsequent years, indicating decreased network fragmentation.

Figure 3, with links colored to represent different communities, reveals a cohesive South American community in the first triennium. Additionally, there are two communities strongly tied to geographic location—Asian and some European countries. Notably, highly central countries do not limit their publications to neighboring nations. In the second triennium, there are still communities formed by nearby countries, such as South American and European, albeit in smaller proportions than the previous period.

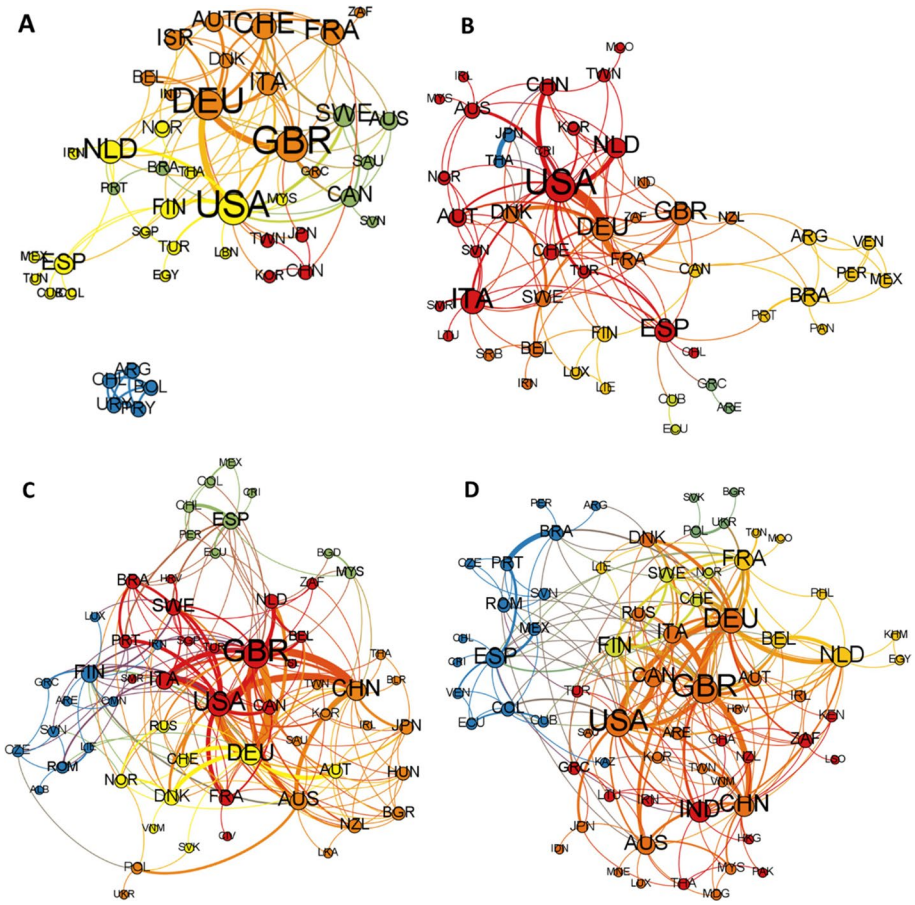

Fig. 3 Evolution of co-authorship networks for publications between countries per triennium, during 2008–2019*, on "innovation management". The networks represent the **A** 2008–2010 **B** 2011–2013 **C** 2014–2016 **D** 2017–2019 trienniums*. *Publications up to August 2019 were considered. The links between two countries were mapped according to the co-authorships of their respective authors. To facilitate the visualization of the networks, only countries that possess co-authorships with other authors from different countries are presented. Each node represents a country, and their size and caption are proportionate with their degree of centrality within each network. The country abbreviations were defined based on the ISO ALPHA-3 Country Code. The width of a link represents its weight. The colors represent the community distribution according to Gephi

Table 2 Analysis metrics for co-authorship networks of publications between countries per triennium, during 2008–2019*, on "innovation management" in the Web of Science and Scopus databases, after removing duplicates

	2008–2010	2011–2013	2014–2016	2017–2019*
Number of nodes (countries)	44	48	60	69
Number of links	109	120	209	224
Average degree	4.955	5	6.967	6.493
Average path length	2.362	2.659	2.351	2.492
Modularity	0.367	0.303	0.217	0.277
Number of communities	5	6	5	6
Density	0.115	0.106	0.118	0.095

*Publications up to August 2019 were considered

Building upon this perspective, Fitzgerald et al. (2021) offer additional evidence by observing that while communities within the global collaboration network were historically rooted in geopolitical or colonial affiliations before 2000, more recent patterns show a shift towards organizing countries into regional partitions.

Individual scope metrics: countries that stand out

For this analysis, individual scope metrics will be considered, that is, related to the network node—which, in this case, represent the country. These measures consider the different ways an agent interacts and communicates with the rest of the network. The most important or prominent agents are usually located in strategic positions within the network (Wasserman & Faust, 1994).

For individual-level analyses, it is recommended to focus the analysis on the centrality of the network, since it can display the extent of an individual's access to resources (Sparrowe et al., 2001). The centrality of a point can be local or global. Local centrality refers to the importance of one focal point in its surroundings, while global centrality refers to the point's prominence within the entire network. Local centrality is measured through degree centrality, while global centrality is measured through betweenness centrality and closeness centrality. Studies show that the distribution of betweenness values approximately follow a power law, indicating that collaborative networks contain a small number of influential individuals and many peripheral agents (Newman, 2004). Ribeiro et al. (2018) confirm this hypothesis by demonstrating a scale-free distribution of node degrees within a global collaboration network that includes researchers from a wide range of scientific fields.

Thus, to identify the most relevant countries within the co-authorship networks of scientific publications on "innovation management" from the selected databases, two measures of centrality were analyzed: degree centrality and betweenness centrality. Table 3 shows the main countries, according to the measures of centrality evaluated, for each triennium.

In degree centrality, the degree of a node corresponds to the number of link incidents or the number of adjacent nodes. In a co-authorship network, this degree indicates the total number of authors in the network who published in a partnership with a given author. Central nodes, which have greater connections with others, have the possibility of activating a greater number of relationships to obtain resources, and are therefore less dependent (Sparrowe et al., 2001).

As shown by Newman (2004), several authors have examined betweenness centrality in co-authorship networks. The betweenness centrality of a node in a network is defined as the number of shortest paths between other pairs of nodes that pass through it. In a co-authorship network, an author with a high value betweenness centrality indicates that a significant number of partnerships established in the network involve, either directly or indirectly, publications related to this author.

It can be noted that, of the 106 countries that make up the database being analyzed, only a select group of 12 countries stand out. For the four analyzed periods, the USA, DEU and GBR stand out within the two measures of centrality analyzed.

When evaluating degree centrality, the USA and GBR are among the top three in all periods. ITA, CHN and DEU alternate among themselves to complete the group. When

Table 3 Countries with the greatest network centrality measures per triennium, during 2008–2019*

	2008–2010		2011–2013		2014–2016		2017–2019*	
Degree centrality	1. GBR	18	1. USA	23	1. GBR	34	1. GBR	27
	2. USA	17	2. ITA	16	2. USA	26	2. USA	25
	3. DEU	16	3. GBR; DEU; ESP	13	3. CHN;	21	3. DEU	22
	4. CHE	12	4. NLD	12	DEU	17	4. IND	19
	5. NLD	11	5. AUT	9	4. AUS	16	5. CHN	18
					5. ITA			
Betweenness centrality	1. USA	0.241	1. USA	0.300	1. GBR	0.299	1. GBR	0.176
	2. ESP	0.160	2. ESP	0.239	2. USA	0.127	2. USA	0.166
	3. GBR	0.140	3. ITA	0.163	3. CHN	0.108	3. ESP	0.135
	4. NLD	0.133	4. DEU	0.155	4. FIN	0.088	4. DEU	0.134
	5. DEU	0.114	5. GBR	0.138	5. DEU	0.086	5. AUS	0.115

Co-authorship networks for publications on "innovation management" in the Web of Science and Scopus databases were considered, after removing duplicates. *Publications up to August 2019 were considered

Country abbreviations—using the ISO ALPHA-3 Country Code: AUS—Australia, AUT—Austria, CHN—China, CHE—Switzerland, DEU—Germany, ESP—Spain, FIN—Finland, GBR—United Kingdom, IND—India, ITA—Italy, NLD—Netherlands, USA—United States

assessing betweenness centrality, the USA is among the three top positions within all periods, in addition to a strong presence from GBR and ESP. In addition to these three countries, ITA and CHN make up the group highlighted in the first three positions.

Among the analyzed networks, only 12 countries emerged within the top five positions of the examined centrality measures. The identification of agents with high degree and betweenness centralities can serve many purposes, like identifying sources of information on technology trends and helping to identify potential partners for cooperation (Fonseca et al., 2017).

The findings complement those of Isfandyari-Moghaddam et al. (2023), which examined co-authorship networks across all fields. The consistent presence of the USA, Germany, United Kingdom and Spain as active collaborators in both studies underscores the enduring prominence of these countries in scientific collaboration across diverse research domains.

The consistent presence of these countries in key centrality rankings suggests their substantial role within the co-authorship network. This role encompasses both their established connections with other authors and their central positioning within the network's structure. Therefore, while presence in a co-authorship network can be a positive indicator, the present study aims to identify whether it is a determining factor in a country's innovative character.

Countries that stand out and the Global Innovation Index

Scrutinizing how countries serve as intermediaries within co-authorship networks and their corresponding GII rankings can uncover whether nations that play roles as facilitators of scientific collaboration also excel as pioneers in terms of innovation.

The GII's annual reports present analyses that focus on the top 10 countries within the ranking. This approach enables a comprehensive exploration of how these nations' innovation landscapes have evolved over time. For the sake of methodological rigor, this study continues by consistently selecting the 10 countries with the highest ranks in the indices for each year spanning from 2008 to 2019. Table 4 depicts the intersection across

the analyzed periods between the countries that excelled in network metrics and those that stood out in the GII reports for the respective years.

When considering the initial three-year span within the study's scope, ranging from 2008 to 2010, five out of the six countries exhibiting significant centrality measures are categorized as innovators in at least one of the two GII reports published during that timeframe. Germany, the United States, and the United Kingdom secured top positions in the ranking for 2008–2009, while Switzerland and the Netherlands distinguished themselves in both reports.

In the subsequent three-year period, covering 2011 to 2013, out of the seven countries displaying notable centrality measures, only four are classified as innovators in the overall GII ranking. These countries are Germany, the United States, the Netherlands, and the United Kingdom. The latter three nations maintained prominent positions in all three GII reports throughout this period, whereas Germany did not feature among the top 10 in the 2013 ranking.

Across the three-year duration spanning from 2014 to 2016, four out of the six countries showcasing significant centrality measures are likewise designated as innovators in the overall GII ranking, as indicated by reports published during this interval. These countries encompass Germany, the United States, Finland, and the United Kingdom. It is noteworthy that Germany only entered the top 10 of the ranking in 2016, whereas the United States, Finland, and Australia stood out consistently within this time frame.

Upon examining the final period of analysis, among the six countries demonstrating noteworthy centrality measures, merely three of them are classified as innovators in the overall GII ranking. These countries consist of Germany, the United States, and the United Kingdom. It is worth highlighting that each of these countries maintained prominent positions in all GII reports throughout this specific period.

Countries like Finland and Switzerland were considered innovative throughout the studied period, but they only stood out in one triennial span each within the analyzed network assessments. Other countries such as Denmark, Singapore, and Sweden also held prominent positions in the rankings but were not identified as relevant nodes in any of the periods.

Conclusion

While we recognize the importance of networks in other domains, innovation management networks are emerging as a driving force that not only coexists with but also profoundly influences various disciplines. This strategic focus reflects the understanding that the ability to innovate is a determining factor for global advancement and a country's competitiveness, intersecting synergistically across multiple spheres of knowledge.

Through an exploration of the global research landscape in innovation management from 2008 to August 2019, it becomes apparent that the heightened engagement of diverse countries in publications on innovation management, featuring international co-authorship, fortifies global-scale structures. This phenomenon suggests a progressive increase in interconnectivity within the global network, with a diminishing proportion of actors (countries and authors) lacking direct relationships with other entities addressed in the selected publications for this study. This trend facilitates

Table 4 Countries that excelled in network metrics per triennium and top 10 countries at Global Innovation Index reports for the respective years, during 2008–19*

Country	2008–10			2011–13			2014–16			2017–19*		
	Degree centrality	Betweenness centrality	Top10 GII	Degree centrality	Betweenness centrality	Top10 GII	Degree centrality	Betweenness centrality	Top10 GII	Degree centrality	Betweenness centrality	Top10 GII
Australia							✓				✓	
Austria				✓								
China							✓	✓		✓		
Denmark			✓			✓			✓			✓
Finland			✓			✓		✓	✓			✓
Germany	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hong Kong			✓			✓			✓			
Iceland			✓									
India										✓		
Ireland						✓			✓			✓
Israel												✓
Italy				✓	✓			✓				
Japan			✓									
Luxembourg									✓			
Netherlands	✓	✓	✓	✓		✓			✓			✓
New Zealand			✓									
Norway			✓									
Singapore			✓			✓			✓			✓
Spain		✓		✓	✓							
Sweden			✓			✓			✓			✓
Switzerland	✓		✓			✓			✓			✓
United Kingdom	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
United States	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Co-authorship networks for publications on "innovation management" in the Web of Science and Scopus databases were considered, after removing duplicates. *Publications up to August 2019 were considered

the dissemination of knowledge in innovation management, potentially fostering the adoption of best practices across countries.

Despite the growing number of participants and connections, we see that the average path length stays low, and the clustering coefficients in these networks are notably higher than one would anticipate in random networks of similar size. The combo of a short average path length and high clustering, reflected in low modularity, makes innovation production easier by reducing the distance between actors, granting the network access to a wider range of knowledge resources. Consequently, it can be inferred that among countries engaging in co-authorship, there's a quick flow of information between connected actors, promoting the spread of knowledge in innovation management. This info, coupled with the resources available in these countries, might create an environment ripe for adopting best practices in the innovation process.

Upon examining co-authorship networks among countries, consistent patterns in degree centrality and betweenness centrality metrics emerge across the analyzed periods, with a focus on 12 specific countries. In terms of degree centrality, the United States and the United Kingdom consistently occupy the top three positions, signaling a substantial engagement in international scientific collaborations over time. Italy, China, and Germany rotate to complete this distinguished group, underscoring the significance of these nations in the formation of global scientific collaborations. In terms of betweenness centrality, the United States continues to exhibit prominence, consistently ranking among the top three in all periods. The noteworthy presence of the United Kingdom, Spain, Italy, and China in this context suggests these countries play pivotal roles as intermediaries in scientific partnerships, serving as conduits for the dissemination and interconnection of knowledge. These patterns underscore the complex and globalized dynamics of co-authorship networks, wherein specific actors assume central roles in the interlinking and diffusion of knowledge at an international scale.

While Brazil is prolific in publishing on "innovation management," it does not rank among the most influential countries based on the metrics analyzed. This suggests potential challenges in attracting co-authorships or a lack of policies fostering research partnerships with international entities. Establishing innovation guidelines could enhance Brazil's innovation ecosystem, fostering collaboration among businesses, universities, research institutions, and stakeholders.

Upon examination of nations that exhibited prominence in both centrality metrics and the GII across the triennial intervals of the study, a persistent presence is observed for three countries: Germany, the United Kingdom, and the United States. These countries consistently demonstrate prominence and high performance throughout all scrutinized periods. Noteworthy is the strategic positioning of the Netherlands in the network, standing out in two triennial periods, implying its influential and distinctive role within the analyzed landscape.

The conclusion of this analysis revealed an intriguing and intricate observation regarding the study's hypothesis, specifically the relationship between a country's prominent central position in the co-authorship network and its innovative character, as reflected in the GII rankings. Table 5 provides an analysis of the percentage of countries that demonstrated the relationship.

It is correct to state that occupying a central and relevant position within the co-authorship network partly imply having an innovative character. Likewise, innovative countries do not necessarily always hold prominent positions in network centrality. Analyzing co-authorship networks appears to be one element that contributes to this understanding, but it alone a broader set of factors needs to be considered to fully assess a nation's innovation capacity.

Understanding the dynamics of these networks can inform policies aimed at fostering collaboration and knowledge exchange in innovation. Governments and organizations can use this knowledge to design strategies that promote interdisciplinary cooperation, leading to more impactful research outcomes and faster diffusion of innovative practices. To effectively foster innovation linkages and assess their impact, policymakers must comprehensively understand ecosystem dynamics. Successful implementation of guidelines for innovation projects necessitates active engagement from diverse stakeholders—government, research institutions, the private sector, universities, and civil society.

Identifying key players and influential nodes within these networks can help stakeholders forge strategic partnerships and leverage expertise from diverse domains, thereby enhancing their innovation capabilities. Additionally, insights gained from analyzing co-authorship networks can guide resource allocation and investment decisions, directing funding towards areas with the highest potential for innovation and collaboration. Overall, a deeper understanding of co-authorship networks in innovation management can facilitate more effective knowledge sharing, collaboration, and innovation, ultimately driving economic growth and societal progress.

By identifying countries excelling in both centrality metrics in collaboration networks and the GII, these nations can be explored as strategic partners to foster innovation through scientific and technological cooperation. This may involve establishing researcher exchange programs, jointly funding research and development projects, and crafting policies to facilitate knowledge and technology transfer between countries.

On the other hand, the finding that not all countries with high centrality in collaboration networks are consistently classified as innovators in the GII highlights the need for a broader approach in assessing a country's innovation capacity. This includes considering factors such as investments in research and development, regulatory environment, innovation infrastructure, education, and entrepreneurial culture.

Ultimately, this discovery emphasizes the importance of an integrated and adaptive approach in promoting innovation on a global scale, recognizing the complexity and interconnectedness of different elements driving a country's innovative success.

Table 5 Percentage survey of nations eminent in comparative analysis

	Countries highlighted in networks	Countries highlighted in GII	Total number of distinct countries	Countries highlighted in both analyses	%
2008–2010	6	16	17	5	29.4%
2011–2013	7	17	20	4	20%
2014–2016	7	16	18	5	27.7%
2017–2019*	6	17	19	4	21%

Considering the existing knowledge on the topic, the analysis of co-authorship networks in innovation management articles holds key implications for academic research. Firstly, it underscores the importance of interdisciplinary collaboration, allowing researchers to leverage diverse perspectives and address complex innovation challenges effectively. Secondly, it provides insights into the structure and dynamics of academic communities focused on innovation, guiding researchers in identifying emerging trends and areas for further investigation.

The results reported represent only a small fraction of what could be accomplished with the data. Although research has primarily focused on network structure, in many systems the nodes themselves have special properties that carry significant information about their role in the network topology. A academic implication of this finding is the potential for further research could delve into node-specific properties within national borders, explore links involving globally significant institutions, and conduct comparisons with other innovation indices for a comprehensive understanding of global innovation dynamics.

Furthermore, a prospective research endeavor may involve a thorough examination of the mechanisms behind temporal gaps. This could include scrutinizing how public policies respond to and integrate discoveries, how business practices adapt, and how socio-economic dynamics influence the effective implementation of these findings within a national context.

Abbreviations

GII Global Innovation Index
SNA Social Network Analysis
WoS Web of Science

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Not applicable.

Author contributions
Each author has significantly contributed to the conceptualization of the work. CP and MF were involved in the design of the study, with CP overseeing the acquisition of the dataset. Both CP and MF were responsible for the analysis and interpretation of data. CM contributed by providing the research software. CP authored the work, and all authors actively participated in substantial revisions and adjustments. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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