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Managing social capital networks in digital international innovation ecosystems

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Abstract

This study operationalizes the concepts of social capital theory through social network analysis. By using this methodology, this research aims to deepen the understanding of how the dynamics of social capital networks are related to the consolidation and sustainability of innovation ecosystems, particularly in the context of digital entrepreneurship platforms. This case study focuses on the International Entrepreneurship Lab Smart Money (IELSM), a digital platform comprising more than 100 organizations from various sectors and countries, mostly in Latin America. Three network subsets around business models were constructed through in-depth interviews with key actors in the IELSM platform. Subsequently, five structural characteristics of the networks were studied via quantitative analysis: ecosystem connectivity, reciprocity, resistance to linkages across sectors, stakeholder diversity, and resource flow difficulty. Based on correlational analysis, a composite index that reflects the maturity of the social capital network is proposed. When applied in similar contexts, this index can provide a comprehensive understanding of social capital dynamics and guide the development of effective strategies for network management. Our findings revealed a strong correlation between reciprocity and ecosystem connectivity. This suggests that a network with greater social cohesion generates more links in which organizations share resources bidirectionally, representing significant potential for mutual value creation. Negative correlations between reciprocity and stakeholder diversity, as well as between ecosystem connectivity and stakeholder diversity, highlight intersectoral cooperation challenges. Social capital networks exhibit complex, nonlinear growth linked to variations in behavior and structure, highlighting the practical implications for managing innovation ecosystems.

JEL Classification 036 · L14 · L26 · O30

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1 Introduction

In entrepreneurial activity, digital technologies are increasingly used to carry out the processes required to start a new business (Giones and Brem 2017). Therefore, digital technologies are directly related to companies' competitiveness, mainly due to their potential to connect different actors and foster stakeholder collaboration (Parviainen et al. 2017). In this context, digital platforms for entrepreneurship have emerged as virtual spaces that foster innovation through digital connections between different types of organizations, such as universities, companies, and government agencies, regardless of their geographical location.

The formation and development of business cooperation networks with universities and other actors have long been a topic of great relevance in the business field (Johnston and Huggins 2018; Kaklauskas et al. 2018; Solleiro and Gaona 2012), and today, these collaborative business networks are positioned as one of the main conditions for companies to reduce the degree of uncertainty and complexity posed by the digital era (Azagra-Caro et al. 2017).

According to (Spigel 2017), Roundy et al. (2018), and Theodoraki et al. (2023), the creation and extension of relationships between groups of networks of actors that share resources and knowledge within digital entrepreneurship ecosystems continue to be one of the challenges of studies in the field of innovation. This research was conducted within the framework of innovation ecosystems, encompassing all the actors involved in the entrepreneurial processes where innovation, creation, and development of new entrepreneurship are promoted (Isenberg 2011; Spigel 2017). From an ecosystem perspective, actors constitute a social network wherein their relationships are shaped by common objectives that lead them to link with each other (Gatica et al. 2015). This approach underscores the importance of connectivity, prioritizing collaboration, and coproduction of value (Smorodinskaya et al. 2017).

Granstrand and Holgersson (2020) reported that some of the main features of innovation ecosystems include the coevolution of organizations' capabilities, which is generated by a shared set of technologies, knowledge, or skills. It is also characterized by dependencies among its members, a standard set of goals and objectives, and shared knowledge and capabilities.

Many scientific reports have been published addressing the complexity and dynamics of entrepreneurship and innovation ecosystems. However, relevant studies related to the efficient role of social capital in network formation continue to be identified, such as in the work of Reingen and Burt (1994), who emphasized the value of information in the flow of knowledge and resources within networks. Spigel (2017), Roundy et al. (2018), and Baroncelli et al. (2024) have provided contributions that seek to clarify the degree of complexity of business ecosystems, first through identifying new external and internal components or factors that influence the ecosystem, with sustainability standing out over time as one of the external aspects with the most significant influence. Internally, ecosystem management can be regulated more efficiently by identifying and understanding the impact of external factors (Roundy et al. 2018). This

theoretical perspective has given way to the analysis of networks, which allows the identification of abstract elements of ecosystems, such as reciprocity or the resource flow difficulties between actors.

Theoretical advancements in understanding innovation ecosystems have left questions regarding ecosystem actors' effective utilization of social capital. To explore these gaps in the dynamics and development of ecosystems, we considered the contributions of Aalbers et al. (2013) and Phelps et al. (2012). Phelps et al. (2012) focus on the structural aspects of the ecosystem and attempt to connect the value of social capital in knowledge and resource-sharing networks. However, this strand of research has yet to extensively explore the strategic implications for ecosystem functioning. Moreover, Aalbers et al. (2013) recognize the intricate nature of ecosystems, highlighting the activation of networks in the diffusion of knowledge and resources. Through a comprehensive review of diverse perspectives, this study aimed to monitor ecosystem behavior, although uncertainties remain about the impact of knowledge use on ecosystem sustainability.

In this research, digital collaboration networks are a contextual imperative with which it is possible to identify and operationalize conceptual constructs that explain the dynamics of entrepreneurship ecosystems and the innovation performance of individual actors based on the characteristics of their networks (Valk and Gijbers, 2010).

Social capital is the primary construct that addresses relationships for mobilizing and sharing resources within and between groups of networks, as well as privileged access to specific channels of knowledge and finance (Maurer and Ebers 2006; Reingen and Burt 1994).

This article analyzes a case study of the International Entrepreneurship Lab Smart Money (IELSM). This platform was selected because it encourages the formation of specialized networks to promote new international business models by involving stakeholders interested in networked entrepreneurship. In 2023, the Association for Education, Science, and Innovation *Stifterverband* recognized this digital platform in Germany as one of the ten most innovative and impactful digital platforms among 186 projects.

This digital academic platform brings together more than 100 organizations, including universities, SMEs, companies, consulting firms, regional development banks, business confederations, and government agencies. The IELSM platform has undergone seven phases in which more than 1250 participants, including international students, entrepreneurs, academics, experts, and consultants, have collaborated in developing more than 40 business models.

The IELSM mainly supports collaborative networks for international entrepreneurship, which promotes cooperation between companies worldwide. According to Balland et al. (2022) and Krom et al. (2022), global networks such as this are potential research resources for understanding the complexity and new dynamics of innovation and entrepreneurship in the context of digital platforms.

The present methodology is based on social network analysis (SNA), which is positioned to address the complexity of the relationships between social entities. This approach is focused on discovering existing interaction patterns between actors in networks (Tabassum et al. 2018). Therefore, SNA is used here to analyze

the social capital networks that compose the IELSM innovation ecosystem and the dynamics established between the organizations that belong to it.

Through in-depth interviews with key actors in the IELSM platform, qualitative information was collected to construct subsets of the network that describe the collaboration dynamics around three business models developed within the platform. Subsequently, a quantitative analysis of the subsets was carried out, which led to identifying structural attributes of the social capital networks. Using primary and secondary data has allowed the creation of an index that reflects the maturity of the social networks within the ecosystem. This index and the analysis of social capital's structural characteristics and dynamics can minimize the uncertainties left by previous work related to innovation ecosystems.

The article is organized as follows: First, the theoretical background, which focuses on the social capital theory, is discussed. Subsequently, the methodology is introduced, starting with the description of the case studies, followed by the research method: social network analysis, network construction, and the operationalization of the variables. Then, we introduce the findings, followed by the development of the social capital maturity index, discussion, practice implications, limitations and directions for future research, and concluding remarks.

2 Theoretical background: social capital theory

Social capital comprises the social resources a person or group can mobilize through relationships and connections. Coleman (1988) emphasizes that social capital is a resource that allows individuals to access resources and opportunities immersed in the social structure, specifying that forms of social capital can influence individual actions and outcomes at the systemic level.

From Ronald Burt's perspective, social capital comprises the relationships and connections a person or organization establishes with others, forming a shared resource among all the parties involved (Burt 2004). The importance of social capital lies in opportunities that allow the transformation of financial and human capital into economic benefits generated through these relationships. As a result, social capital is considered a determining factor in competitiveness, and its value is comparable to that of financial and human capital (Reingen and Burt 1994).

The connection between social capital and competitiveness is linked to the access to privileged information, resources, and opportunities that actors acquire due to their connections with others. The management of these connections allows them to generate strategic alliances to obtain support from other actors in the network (Reingen and Burt 1994).

Social capital directly contributes to reducing transaction costs between companies or actors since it reduces the costs of information search, negotiation, decision making, and surveillance. Therefore, social capital is considered a tool to facilitate coordination and collaboration among actors involved in innovation processes (Amara et al. 2002).

The position of the actors refers to the quality of the relationships they establish with others; for this reason, strength, trust, and reciprocity depend on the depth

of the social relationships. Consequently, there will be mutual trust in a high-quality relationship, which generates a reciprocal exchange of resources, support, and continuous collaboration. Actors in central positions have high-quality relationships with other central actors. In contrast, actors in peripheral positions establish low-quality relationships where they are more cautious in sharing information and resources (Reingen and Burt 1994, p. 63).

The theory of social capital is the basis for the development of research on interpersonal and interorganizational collaboration networks, which seeks to explain the innovation performance of individual actors based on the characteristics of their networks. Among the applications are the identification of critical actors in the network, the identification of gaps as an area of opportunity to improve performance, and the identification of collaboration patterns to increase network efficiency and effectiveness. Studies in this field allow a better understanding of how collaborative networks affect innovation performance and what factors enhance or inhibit collaboration (Valk and Gijbers 2010).

Within innovation studies, several theories support the importance of social capital by recognizing that connectivity among actors is the basis for enhancing entrepreneurship and innovation. The triple helix model and subsequent models based on it seek to understand the dynamics of the variety of institutions involved in innovation systems through the agreements and policies between actors, emphasizing the importance of cross-sectoral collaborative links between key institutional spheres: academia, industry, and government (Leydesdorff and Etzkowitz 1998). The national innovation systems approach proposed by Lundvall (1992) also highlights the importance of considering the systemic interdependence between independent economic actors whose articulation makes it possible to generate innovation.

Similarly, open innovation highlights the importance of using external ideas and technologies to accelerate innovation processes (Chesbrough 2003), which is directly linked to social capital, since collaboration with external stakeholders is fundamental.

The social capital theory is also complemented by organizational theories and constructs such as absorptive capacity, defined by Cohen and Levinthal (1990) as the ability of a company to recognize the value of external information, assimilate it, and apply it. In turn, the theory of dynamic capabilities proposed by Teece et al. (1997) highlights the importance of integrating external elements with the organization's internal abilities to respond to the changing nature of the context.

3 Method

3.1 Research method: social network analysis

Social network analysis is a qualitative and quantitative model research approach focused on studying relationships and social structures through the graphical representation of interactions between actors (Wasserman and Faust 1994). This methodology helps to describe the dynamics of ecosystem development and allows us to identify moments that highlight the sustainability of the ecosystem through the

activation of social capital. According to Granovetter (1973), social network analysis helps examine the relationship between small-group interactions and large-scale social patterns. It allows an understanding of how broader social structures are generated from individual interactions, thus linking sociological theory's macro- and microlevels.

Social network analysis aims to comprehend network structures by identifying patterns of interaction and understanding the distribution of connections in the network (Alcaide Lozano et al. 2019). This approach is utilized in innovation studies to map actors and technologies, offering insights into innovation dynamics such as collaboration, communication, and technology networks (Valk and Gijbers 2010).

Two types of variables are needed to understand a social network. Compositional variables refer to the individual characteristics of the actors in the network, and structural variables refer to the properties and characteristics of the network itself (Wasserman and Faust 1994). As shown below, this article analyzes the structural variables of networks at the organizational level.

3.2 Case study description

We selected the IELSM for this study because it is an emerging international innovation ecosystem. This digital academic platform brings together more than 100 public and private organizations from academia, industry, and government.

This project emerged in 2020, just in the year the COVID-19 pandemic started in Germany. Since its launch, more than 1,250 people have participated. The IELSM is an academic initiative at the Business & Law School of Berlin (BSP) that aims to promote international entrepreneurship, support entrepreneurs, and train students to design business models (Estrada and Novelo 2023). The platform seeks to create, accelerate, and internationalize entrepreneurial business models through co-creation with multicultural work and teams of students, entrepreneurs, and experts.

The study examines subsets of the IELSM network through the seventh phase, which ends in February 2024. This approach was chosen to examine the dynamics of the business models of small- and medium-sized companies.

As Fig. 1 shows, the organizations that comprise the social capital networks analyzed in the case studies are from Argentina, Honduras, Chile, Colombia, Costa Rica, Cuba, Ecuador, Germany, Kenya, Mexico, Panama, Peru, Scotland, Spain, the USA, and Venezuela. More than 90% of network organizations are from Latin American countries.

The criteria for selecting the business models were that they show progress in internationalizing the product or service offered to the market, report the generation of business alliances with other ventures participating in the platform, and have participated in at least four consecutive phases within the platform.

Case 1, corresponding to the first subset (C1), offers small- and medium-sized enterprises digitalization services. It has expanded its operations to the international market and has generated alliances with other organizations within the IELSM innovation ecosystem. The analysis of this subset considers its participation in 5 phases within the IELSM.

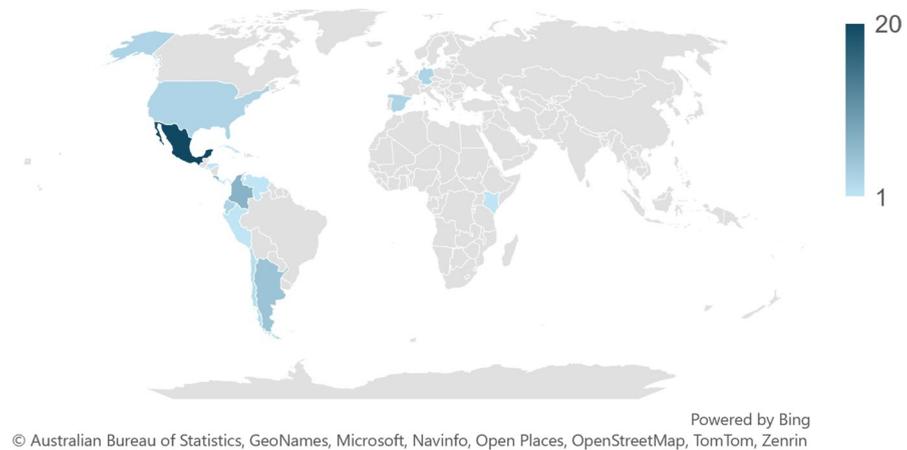


Fig. 1 Organizations by country of origin. Note: The color scale is distinguished according to the number of organizations per country

The second case (C2) offers specialized human resources services linking trained personnel with the international labor market and has been developed within the IELSM ecosystem from phase 4 to phase 7. Finally, the third subset (C3) corresponds to the ecotourism sector. It is a social innovation project because it links local impacts to agricultural communities in Latin America while promoting sustainable international tourism. This business model has been developed in the IELSM from phase 2 to phase 7.

3.3 Data collection and network construction

For the collection of qualitative information, primary sources were used. A series of five in-depth interviews with the managers of the IELSM platform explored existing partnerships and forms of collaboration among platform organizations. The interviews began with the following question: What organizations have collaborated on the business model, and how have those collaborations evolved over time? Based on the responses, we delved into the names of the organizations, the specific phases in which the organizations collaborated, the business activity in the case of the business sector organizations, and the activities they have undertaken together.

For the construction of the networks, the qualitative information was complemented with the database of attendance records of virtual meetings and other activities involving co-creation processes of the three previously selected business models.

This study analyzes network graphs at the organizational level, composed of two fundamental units: vertices, which represent organizations, and edges, which are the links between organizations. In the built networks, seven types of organizations are distinguished by color: universities, SMEs, companies, consulting firms, regional development banks, business confederations, and government agencies. The size of

the vertices varies according to the degree, an attribute that represents the number of connections the organization has with others in the network.

While edges are the connections between vertices, two types of edges are distinguished: directed and undirected. Graphically, the directed edges are represented by arrows, which establish the direction of shared resources (Tabassum et al. 2018, p. 4). Another distinction in the edges is the weight, which is used to reflect how close the link is and the intensity or frequency of the interaction. In social capital networks, the edge weight refers to the intensity with which resources are exchanged and the strength of the bond between actors.

In the networks analyzed, directed links are used when one organization shares resources, while the other only receives resources. Moreover, undirected links are established when both organizations exchange reciprocally. In addition, directionality is used as a reference to determine the weight of the edges since the mutual exchange of resources is a particularity of the most substantial relationships within the network.

3.4 Operationalization

To begin the analysis, we operationalized the variables linking the theoretical concepts related to social capital network consolidation to the structural variables for the analysis of social networks, as shown in the table (Table 1).

Based on the theoretical concepts and the calculation of SNA attributes, the formulas shown in Table 2 were used to calculate the network characteristics of the three case studies analyzed.

4 Findings

4.1 Network configuration and dynamics

Figure 2 shows the graphical representations of the social capital networks formed by the organizations participating in the business models of the three case studies.

In the first case study, there is evidence of gradual growth in the inclusion of new organizations in the network as the business model's participation in the IELSM platform progresses. At the initial stage of business model implementation (phase 3 of the IELSM platform), the network consisted of 12 organizations. However, in phase 7, this network experienced a significant increase with the participation of 26 organizations, representing an increase of almost 117%, indicative of an expansion of the network.

Figure 3 shows the behavior of the network features of case 1 in each of the phases within the IELSM ecosystem. Among the outstanding features of network development was the diversity of stakeholders, which doubled in the last participation phase. There was also a decrease of approximately 80% in the resistance to linkages between organizations in different sectors. Concurrently, there was a 54% reduction in difficulties related to resource flow.

Table 1 Association of SNA attributes with theoretical concepts

Theoretical concept	Definition	SNA attribute	Definition	Network feature
Ecosystem Connectivity (Rocha et al. 2022)	The quality and quantity of connections between key players in the ecosystem, including companies, academic institutions, research centers, and others	Density	The ratio of existing connections to the total number of possible connections	Ecosystem Connectivity
Reciprocity in relationships (Granovetter 1973)	It measures the proportion of reciprocal exchanges in social relationships Reciprocity can be fundamental to the development of long-term relationships and the building of lasting social capital	Reciprocity	The ratio of bidirectional (reciprocal) connections to the total number of connections	Reciprocity
Stakeholder Diversity (Feldman and Zoller 2012; Reingen and Burt 1994)	Evaluate the number of links between actors of different profiles to address links between the business and academic sectors	Homophily Index	The tendency of nodes in a network to connect with others that are similar to them in some specific attribute	Resistance to linkages across sectors
Group cohesion (Reingen and Burt 1994)	Indicates the existence of well-connected communities that share resources and information more efficiently	Demographic diversity Average path length	A variety of demographic attributes (e.g., type of actor) present in the network nodes Measure of the efficiency of communication or information propagation in the network	Stakeholder Diversity Resource flow difficulty

Table 2 Network feature formulas

Network feature	Formula
Ecosystem connectivity (Ec)	$Ec = \frac{\text{Number of existing edges}}{\text{Total possible of links}} = \frac{\text{Edges}}{\frac{n!}{2!(n-2)!}}$ <p>$n =$ existing vertex in the network</p>
Reciprocity	$Rc = \frac{\text{Number of undirected edges}}{\text{Total possible of links}} = \frac{\text{Undirected Edges}}{\frac{n!}{2!(n-2)!}}$ <p>$n =$ existing vertex in the network</p>
Resistance to linkages across sectors (H)	$H = \frac{\text{Number of homophilic edges}}{\text{Total possible of links}} = \frac{e_i}{\frac{n!}{2!(n-2)!}}$ <p>$e_i =$ edges between vertices of the same type $n =$ existing vertices in the network</p>
Stakeholder diversity (D)	$D = \frac{\text{Types of vertex existing in the network}}{\text{Total possible vertex types}} = \frac{v_n}{v_t}$ <p>$v_n =$ number of vertex types in the network $v_t =$ total number of types of organizations</p>
Resource flow difficulty (Rfd)	$Rfd = \frac{\text{Distance between each vertex and the others}}{\text{Number of existing paths between vertices}} = \frac{\sum d(v_i, v_j)}{p}$ <p>$d(v_i, v_j) =$ Distance between nodes $p =$ number of the actual paths</p>

The resource flow difficulty calculation is based on the average length path metric using the software Gephi

Case 2 is the business model with the briefest trajectory within the IELSM. However, network expansion is evident, increasing from 9 organizations in phase 4 to 19 in the 7th. The graphical representations of the networks of case 2 (Fig. 2) illustrate the growth of this network while showing an apparent increase in the diversity of the participating organizations. The increase in network expansion was more than 110%, and the increase in diversity was 96.5%.

As shown in Fig. 4, case 2 presented more significant difficulties in resource flow than case 1. This network presented an almost 25% decrease in challenges related to the flow of resources. It is also observed that the network diversity changes abruptly, particularly in phase 6. Similarly, a decrease of approximately 72% was observed in the resistance to establishing connections between organizations from different sectors.

Case 3 presented the most significant expansion in the first stages of its trajectory between phases 2 and 3; the network registered a growth of 160%. However, from phase 3 to phase 7, only an increase of 54% was observed. On the other hand, the network’s diversity grew by 50%.

Figure 5 shows the behavior of the network features of case 3 in each of the phases within the IELSM. Among the outstanding characteristics of case 3 is the increase in the difficulty of resource flow, which increased by 46% between Phase 2 and Phase 7. On the other hand, resistance to linkages among stakeholders decreased by 92%.

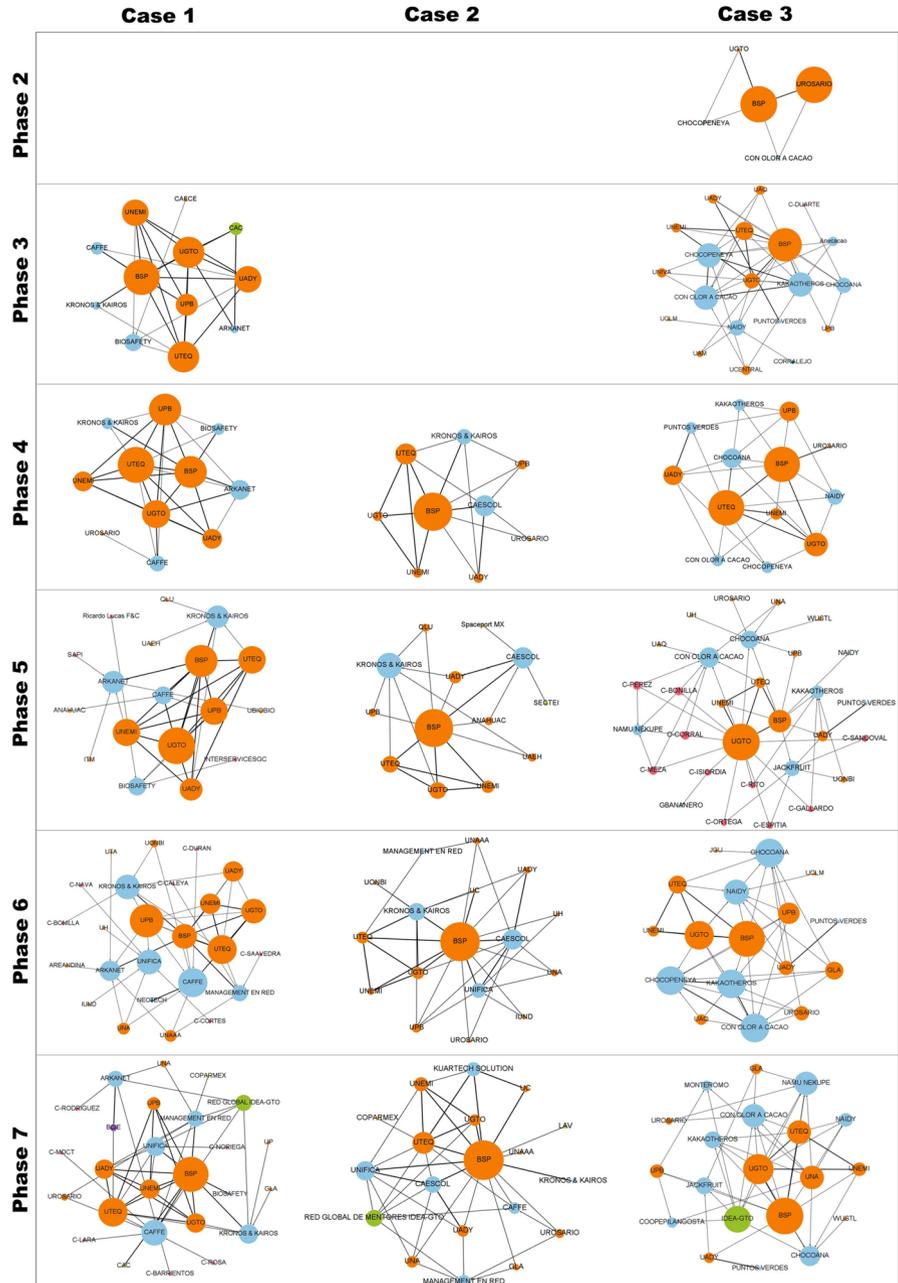


Fig. 2 Social capital networks. Note: This figure shows the graphs of the social capital networks in all the case studies in each phase. The graphs were generated using Gephi software

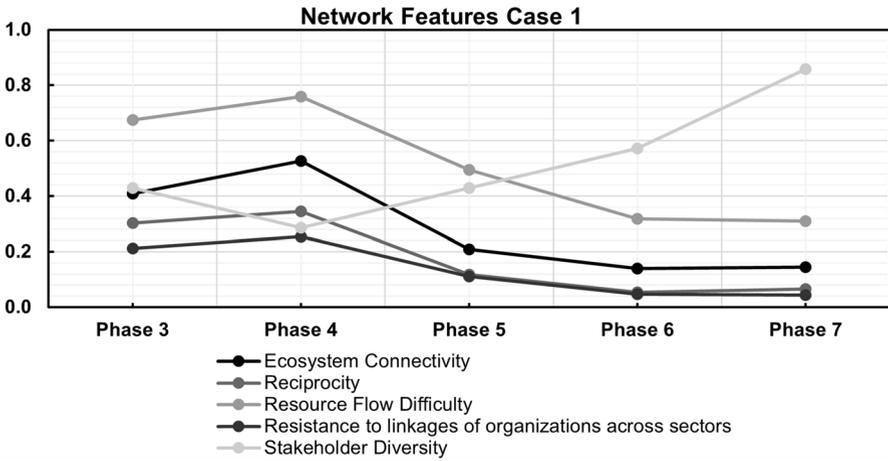


Fig. 3 Features of social capital networks case 1

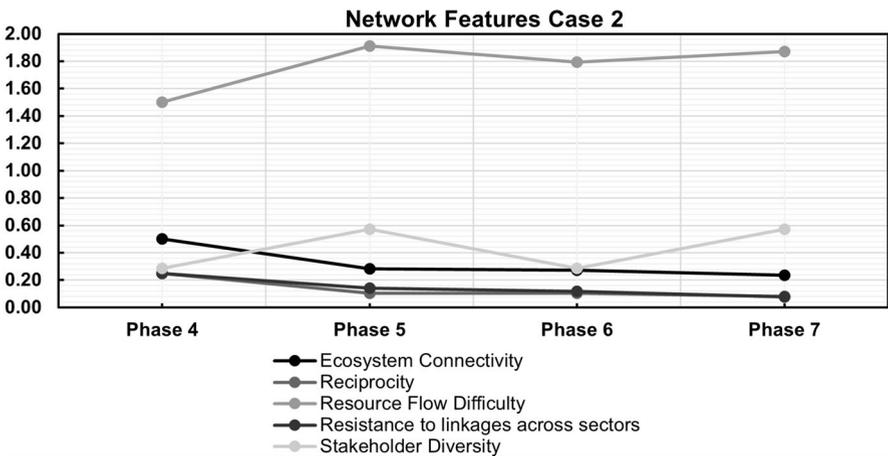


Fig. 4 Features of social capital networks case 2

4.2 Building the maturity index of social capital networks

The attributes of each network of the three case studies were used to construct the maturity index. Table 3 shows the network features presented by the case studies in each phase of their participation in the IELSM.

Correlation analysis was carried out between variables, the results of which are detailed in Table 4.

These correlations show the complexity of social capital management in innovation ecosystems. The analysis revealed a solid positive correlation between

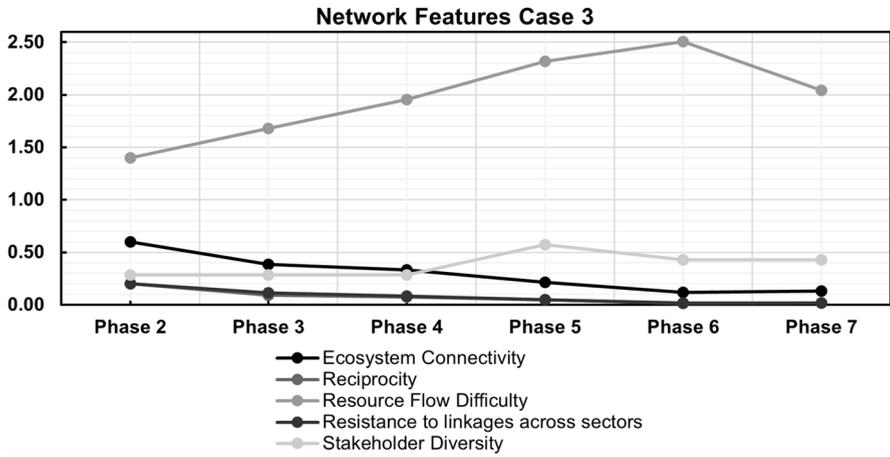


Fig. 5 Features of social capital networks case 3

Table 3 Social capital networks attributes

Network	Ecosystem connectivity	Reciprocity	Resource flow difficulty	Resistance to linkages across sectors	Stakeholder diversity
C1Phase3	0.409	0.303	0.675	0.212	0.429
C1Phase4	0.527	0.345	0.758	0.255	0.286
C1Phase5	0.209	0.118	0.494	0.111	0.429
C1Phase6	0.140	0.053	0.317	0.047	0.571
C1Phase7	0.145	0.065	0.310	0.043	0.857
C2Phase4	0.500	0.250	1.500	0.250	0.286
C2Phase5	0.282	0.103	1.910	0.141	0.571
C2Phase6	0.272	0.103	1.794	0.118	0.286
C2Phase7	0.234	0.082	1.871	0.076	0.571
C3Phase2	0.600	0.200	1.400	0.200	0.286
C3Phase3	0.385	0.090	1.679	0.115	0.286
C3Phase4	0.331	0.074	1.956	0.081	0.286
C3Phase5	0.216	0.047	2.316	0.047	0.571
C3Phase6	0.117	0.014	2.508	0.018	0.429
C3Phase7	0.132	0.016	2.042	0.016	0.429

three pairs of variables: reciprocity and ecosystem connectivity (0.82), ecosystem connectivity and the variable resistance to linkages across sectors (0.90), and reciprocity with resistance to linkages across sectors (0.95).

The association between reciprocity and ecosystem connectivity suggests that a network with greater social cohesion also generates a more significant number of reciprocal links where organizations share resources bidirectionally, representing considerable potential for mutual value creation.

Table 4 Correlation of structural attributes of the networks

	Ecosystem connectivity	Reciprocity	Resource flow difficulty	Resistance to linkages across sectors	Stakeholder diversity
Ecosystem connectivity (Ec)	1				
Reciprocity (Rc)	0.825	1			
Resource flow difficulty (Rfd)	-0.112	-0.426	1		
Resistance to linkages across sectors (H)	0.907	0.950	-0.295	1	
Stakeholder diversity (D)	-0.640	-0.423	-0.265	-0.527	1

On the other hand, the relationship between ecosystem connectivity and resistance to linkages across sectors suggests that networks present greater ease in increasing linkages between organizations in the same sector, thus demonstrating the difficulty of cross-sectoral cooperation. The relationship between resistance to linkages across sectors and reciprocity also indicates that the increase in reciprocal linkages in the networks of the case studies is mainly limited to organizations from the same sector.

In addition, there is a moderate negative correlation (-0.640) between ecosystem connectivity and stakeholder diversity, suggesting that the less diverse the type of organizations within the network, the easier it is to increase their linkages. This trend is confirmed by the negative correlation (-0.423) between reciprocity and stakeholder diversity, which reflects the difficulty for organizations belonging to different sectors to establish linkages with bidirectional resource flow. A similar correlation is established between reciprocity and resource flow difficulty (-0.426), which indicates that networks with more reciprocity experience a reduction in the difficulty of resource flow.

Another relevant correlation is between stakeholder diversity and resistance to linkages across sectors (-0.52), which indicates that networks with more diverse organizations decrease their resistance to generating cross-sectoral linkages.

Similarly, a negative correlation (-0.295) between resource flow difficulty and resistance to linkages across sectors is observed. This reflects that there is more resistance to generating cross-sectoral linkages in networks with less difficulty in resource flow. This suggests that the networks that present less difficulty in the flow of resources are those whose links are established mostly between organizations of the same sector. Thus, within the networks studied, achieving a flow of resources between organizations from different sectors represents a challenge and is an indicator of the maturity of the innovation ecosystem.

Finally, the negative relationship (-0.265) between stakeholder diversity and resource flow difficulty stands out. This shows that networks with greater diversity among the types of organizations present a decrease in resource flow difficulty. This evidence can be used to design strategies according to the specific characteristics of the innovation ecosystem.

Table 5 Pairwise comparison matrix (PCM)

	Ecosystem connectivity (Ec)	Reciprocity (Rc)	Resource flow difficulty (Rfd)	Resistance to linkages across sectors (H)	Stakeholder diversity (D)
Ecosystem connectivity (Ec)	1	5	3	5	1
Reciprocity (Rc)	1/5	1	1	1	1/5
Resource flow difficulty (Rfd)	1/3	1	1	1	1/3
Resistance to linkages across sectors (H)	1/5	1	1	1	1/5
Stakeholder diversity (D)	1	5	3	5	1

Based on the analysis of the qualitative information, weights were assigned to the independent variables using a pairwise comparison matrix (PCM). Table 5 shows the PCM values assigned based on the importance of one variable over another.

If the difference is strong (\gg), the value assigned is 5; if it is moderate ($>$), the value is 3; and if the importance is the same ($=$), the value assigned is 1. The relationship between the importance of the independent variables is as follows:

- Ecosystem connectivity = Stakeholder diversity.
- Ecosystem Connectivity $>$ Resource Flow Difficulty.
- Stakeholder Diversity \gg Resistance to linkages across sectors.
- Ecosystem Connectivity \gg Reciprocity.
- Stakeholder Diversity \gg Reciprocity.
- Resistance to linkages across sectors = Reciprocity.
- Ecosystem Connectivity \gg Resistance to linkages across sectors.

Subsequently, the eigenvector (EV) was calculated. The result is shown in the variables' weighting in the proposed mathematical model. For the calculation of social capital maturity ($SC\mu$), ecosystem connectivity, stakeholder diversity, and reciprocity were considered to have a positive relationship with the dependent variable. In the case of the variable resource flow difficulty, an inverse relationship is established. In contrast, the variable resistance to linkages across sectors has a negative relationship.

$$SC\mu = (0.37 * Ec) + (0.37 * D) + \left(0.10 * \frac{1}{Rfd}\right) + (0.08 * Rc) - (0.08 * H)$$

The proposed index has been used as a metric to assess the maturity of the social capital networks for the case studies analyzed. The results of this assessment are presented in detail in Table 6, which records the levels of maturity in each of the phases.

In all cases, the development of the networks does not follow a linear trajectory, making their prediction complex. Case 1 presents consistent growth in maturity. On the other hand, case 2 shows a slight decrease in phases 6 and 7, which indicates that the development of the network stagnates, and actions should be taken to promote its maturity. Finally, case 3 shows a progressive decrease in the maturity of the network, making the emergence of measures to prevent the disappearance of the network crucial. The differences between the trajectories observed in this study provide valuable findings for effectively managing social capital networks in innovation ecosystems.

Table 6 Maturity of the social capital network for each case study

Phase	2	3	4	5	6	7
Case 1	0.00	0.47	0.44	0.44	0.58	0.69
Case 2	0.00	0.00	0.36	0.37	0.26	0.35
Case 3	0.40	0.31	0.28	0.33	0.24	0.26

This table shows the results of the social capital maturity ($SC\mu$) calculation using the proposed mathematical model

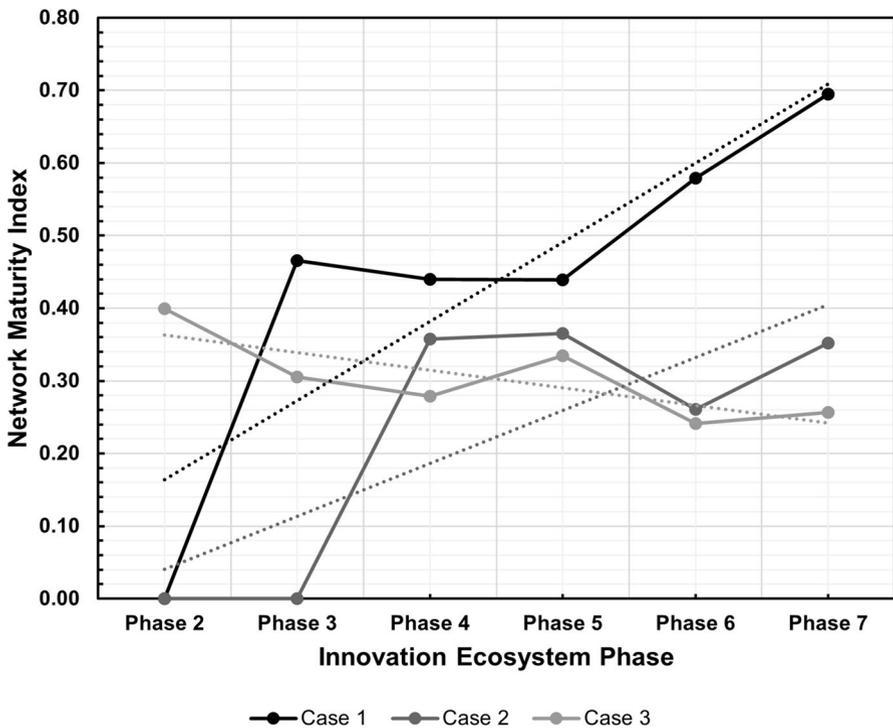


Fig. 6 Assessment of social capital network maturity

Figure 6 illustrates the evolution over time in the maturity of the social capital networks in the three case studies, highlighting significant differences in their trajectories. Case 1 shows substantial development in its later phases compared to earlier phases. Case 2 shows a substantial decrease in phase 6 and an improvement in phase 7, although its increase is insufficient to reach the performance registered in its first phase within the IELSM platform. In contrast, case 3 reveals a decline in the maturity of its network, indicating that despite expanding this business model’s network through its participation in the IELSM, it has not consolidated its social capital network. Addressing the identified shortcomings regarding network characteristics is crucial to enhancing long-term viability.

5 Discussion

The findings reveal the complexity of managing social capital and building innovation ecosystems. Furthermore, the empirical evidence shows the unique nature of each innovation ecosystem, consistent with Satu and Vesa (2018); this demonstrates that it is not feasible to generate a standard strategy to promote their development. As observed in the case studies, social capital networks experience nonlinear growth closely linked to variations in their behavior and structure. For this reason, emphasis

is placed on analyzing the dynamics and particular requirements for their strategic management.

The results of the first case study analysis show that beyond the expansion of the network due to the increase in the number of organizations, maturity is related to the diversity of stakeholders, along with a decrease in resistance to cross-sectoral linkages and a reduction in difficulties for resource flow. According to the above correlations between the characteristics of social capital networks, although ecosystem connectivity does not show significant progress during the development of case one network, cross-sectoral linkages contribute to its maturity by compensating for the number of linkages with strategic links between organizations.

Another behavior observed in case one is the decrease in resource flow difficulties. According to the correlation analysis, this decrease is associated with the increase in stakeholder diversity and the generation of linkages between organizations from different sectors. As mentioned by Pellikka and Ali-vehmas (2016) some benefits of stakeholder diversity for generating interorganizational collaboration are increased profitability, shortened time to market, enhanced innovation capability by knowledge sharing, and expanded market access.

Based on the characteristics of case one, targeted interventions focused on building cross-sectoral collaborative linkages between organizations within the ecosystem are more beneficial to the maturity process than bringing in new organizations from sectors with greater representation. Therefore, strategies for integrating new organizations into the ecosystem should focus on the types of organizations or sectors with less participation. This highlights the importance of developing social capital management strategies that consider the interrelationship between the structural characteristics of networks to achieve the expected results.

The findings of the second case study confirm the mentioned above, indicating that this network, despite its expansion, faces severe resource flow difficulties between organizations, contributing to stagnation in its maturity progress. Specifically, this network faces the prevalence of stakeholder diversity, as it is observed that actors who have contributed to stakeholder diversity do not remain in the network.

The empirical evidence of case two shows that the recognition of the value of being part of the ecosystem is fundamental for the prevalence of the actors; for this reason, the co-creation of value among the actors is closely related to the ecosystem maturity. The strategic management literature has documented a tension between value creation, generated at the ecosystem level, and value capture, which takes place mainly at the organizational level (Oskam et al. 2020). Therefore, this is one of the challenges that requires considering the differences between the objectives and interests of the different types of stakeholders, to generate strategies that enable clear communication of benefits.

Given that the literature reports that for the creation of collaborative networks, the actors must share the belief that together within the network they can achieve objectives that would not be possible individually (Rabelo et al. 2015); effective communication strategies must be implemented to help convey specifically the impact that collaboration has for the achievement of the objectives set by the organizations.

In addition, policies play a crucial role in facilitating the generation of value networks, since this research addresses the case of an international entrepreneurship platform it is necessary to emphasize that existing local policies must be aligned with global trends, so innovation policies must boost local knowledge without losing sight of international interactions (Satu and Vesa 2018).

The third case study exhibits the lowest expansion rate during its participation in the innovation ecosystem. Its decrease in maturity is linked to the great difficulty it presents in the flow of information and resources within the network. In addition, as previously mentioned, an inconsistent improvement in the diversity of stakeholders in this network is observed, a crucial aspect for optimizing the flow of resources.

The results suggest that the characteristics of the innovation ecosystem influence the maturity of social capital networks around business models, as the activities within the ecosystem constitute the context in which relationships between organizations are established. This dynamic is evident in the analysis of the third case, where it is observed that the social capital network shows less development and faces more significant difficulties in expanding. This phenomenon could be related to the level of digitalization of the business model since links of this nature are more easily developed within the IELSM platform, which is a digital platform. This finding aligns with the link established by Sussan and Zoltan (2017) between the level of digitization and the ecosystem's capacity to promote entrepreneurship, so strategies focused on promoting the digitalization of organizations belonging to the ecosystem can also enhance maturity.

The findings suggest that the maturity of innovation ecosystems is closely linked to cooperation between different sectors. This underlines the complementarity of the innovation ecosystem theory approach with the triple helix theory (Leydesdorff and Etzkowitz 2018) and subsequent models that explore collaboration between different sectors. As illustrated in the three case studies, establishing reciprocal linkages remains the principal challenge, especially between organizations from different sectors.

5.1 Practical implications

This study's practical implications focus on managing social capital in the design of innovation ecosystems. The authors recommend analyzing the social capital network's development and maturity. This will enable the identification of specific areas of opportunity and the generation of specific strategies.

For effective social capital management, this article's findings can be complemented by those proposed by Reingen and Burt (1994). By considering the position of the actors within the network, it is possible to identify the organizations generating higher-quality relationships and involve them in strategies to improve the flow of information and resources within the network.

In general, the structural characteristics that have the most significant impact on enhancing the maturity of the network are ecosystem connectivity and

stakeholder diversity. Based on the correlational analysis, the strategies focused on improving ecosystem connectivity and reciprocity imply implementing strategies to promote cross-sectoral cooperation. They also require specific actions to guarantee the prevalence of stakeholder diversity in the network. On the other hand, strategies focused on increasing the diversity of stakeholders within the network have the benefit of decreasing the difficulty in the flow of resources, which allows innovation ecosystem managers to focus their efforts on implementing measures to increase ecosystem connectivity or any other opportunity area.

5.2 Concluding remarks

Based on the above, innovation ecosystem management needs to focus on the detailed study of the particular social capital network to be addressed. Therefore, a key area for improvement lies in developing new methods to analyze more complex networks that facilitate a thorough understanding of the dynamics involved. Strategies cannot be universal; it is imperative to design them while considering the evolution of the network, understanding its structure, and accurately identifying the difficulties hindering its maturity. In this sense, the behavior of networks observed through a plurality of actors coming from different cultures of innovation and entrepreneurship reaffirms, on the one hand, the complexity of the management of international ecosystems and, second, allows us to observe the behavior of the selected categories of analysis in a context marked by digitization. Even when the actors only know each other digitally, motivation and trust are activated to explore cooperation and resource sharing. These networks are not restricted by sector or company size but rather by an attitude toward potential collaboration in which the actors can exchange resources that will allow them to remain and grow in the market.

5.3 Limitations and directions for future research

Notably, the study's scope and generalizability are limited by the characteristics of the selected innovation ecosystem and the number of networks analyzed. Therefore, it is essential to include new case studies of ecosystems based on digital networks to deepen the consolidation processes of social capital networks within innovation ecosystems.

It is also important to note that the networks analyzed are developing under the market pressure observed after the pandemic, in which interaction almost inevitably occurs through digital media. One of the strengths of network analysis is that its findings can be used to develop an accurate transfer of knowledge and resources between organizations. However, it is necessary to delve deeper into the motivations that drive network interactions.

A promising future research direction is exploring the complementarity of empirical studies using computational tools that allow in-depth analysis and more accurate modeling of innovation ecosystem consolidation processes.

Another opportunity for further research is to analyze to what extent countries' intrinsic cultural aspects and the characteristics of innovation culture could influence the dynamics of the creation and development of the selected networks. These are precisely some aspects of ecosystem analysis that have yet to be studied.

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Declarations

Conflict of interest The authors declare no potential conflicts of interest concerning this article's research, authorship, or publication.

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