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REVISTA BRASILEIRA DE GESTÃO E DESENVOLVIMENTO REGIONAL
V.19, N°3, Set-Dez/2023 | Taubaté/SP - Brasil | ISSN 1809-239x

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ANÁLISE DE ESTRUTURA DE REDES DE INOVAÇÃO: O CASO DO PROGRAMA DE INOVAÇÃO TECNOLÓGICA (INOVAFIT)

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Received:07/10/2020
Accepted:07/12/2023

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ABSTRACT

The current research aims to investigate both the structural features and implications of an innovation network based on innovation projects developed by companies promoted by a governmental agency program, within a context focused on promoting innovation in Small and Medium-sized Enterprises (SMEs). Network analysis was carried out based on Industry-University-Research Institute (IUR) interactions, from the Triple Helix perspective. Results have pointed towards a scale-free structure configuration, with some hubs capable of strongly concentrating connections. In addition, the herein-observed high grouping and reduced connective distance between actors have indicated high use of neighbourhood relationships and the need of making small efforts to reach other actors in the network, respectively. Another relevant finding suggested companies' preferential attachment to a few hubs represented by universities with strong centrality power in the network. This structure can lead to greater knowledge redundancy, faster knowledge diffusion speed and greater knowledge distribution in the network, although redundant. Some of the main contributions of the current study comprise the dismemberment of universities and research institutes to analyze the role played by each institutional actor, the implementation of an empirical study focused on investigating the local network of projects undertaken by SMEs, as well as insights to help development agency's actions.

Keywords: Innovation Network. Triple Helix. Social Network Analysis. Subvention Programs. Innovation Programs

INTRODUCTION

Innovation often consists of a dynamic and interactive process involving different actors, which often embodies the form of an innovation network capable of speeding up and amplifying its development (Debresson; Amesse, 1991; Etzkowitz, 2002; Faccin; Balestrin; Bortolaso, 2016). The complexity inherent to this process can influence changes taking place in the economy by both shaping its mechanisms and structures and enabling economic development (Nelson; Nelson, 2002). From this perspective, the approach to relational dynamics between companies and different actors working in the innovation environment gains strength over the approach to innovation as a process limited to internal organization and as an essentially isolated action. It is so, because of the widely accepted idea that companies find it harder to achieve satisfactory innovative performance results when they work alone than when they are involved in cooperative innovation environments (Barrie; Zawdie; João, 2019; Brem; Radziwon, 2017; Debresson; Amesse, 1991; Faccin; Balestrin; Bortolaso, 2016).

If undertaking innovation processes alone does not seem to be a promising option, then, context and relationships matter. Different regions have different regional development levels, according to which, the production structure and dynamics of less developed regions are more dependent on less innovative sectors (Cardozo; Martins, 2020; Pinheiro *et al*., 2022). Innovation strongly depends on policy incentives to promote innovative environments, mainly in less developed countries and regions (Ndabeni, Rogerson & Booyens, 2016).

Thus, the construction of innovation networks capable of articulating Industry-University-Research Institute (IUR) is an important contribution to the development of innovative processes. In addition, government agencies focused on promoting science, technology and innovation stand out as stimulating actors in this process, since they play a fundamental role in the incentive policy aimed at promoting innovation via networks of interactions among different authors (Brem; Radziwon, 2017). Therefore, given cooperation networks' proven positive influence on innovation (Angelini *et al.*, 2017; Debresson; Amesse, 1991; Faccin; Balestrin; Bortolaso, 2016; Franco; Câmara; Parente, 2017) and the relevance of incentive actions deriving from governmental development policies (Brem; Radziwon, 2017; Edler; Fagerberg, 2017; Mazzucato; Semieniuk, 2017), mainly in emerging economies, one can point out a relevant gap in the study of interactions among actors in innovation networks, at project

submission scope, in a governmental agency development program.

The following research question is defined, based on this discussion: what are the structural features of innovation networks built from company innovation projects subsidized by governmental agencies? In order to answer this question, it is necessary to understand how the network of Small and Medium-sized Enterprises' (SMEs) projects is structured at a local level, as well as the role played by each institutional actor category. In order to do so, the case of a governmental program focused on promoting innovation in the state of Ceará, which is a poorly developed state in Northeastern Brazil, was herein used as a sample. Recent policies have adopted the perspective of creating a better environment for innovation, mainly in the state of Ceará. Thus, a systematic program focused on funding innovation projects for SMEs, in collaboration with Scientific and Technological Institutions (STIs), has been implemented through the state's scientific and technological development agency, since 2015. Therefore, investigating incentive networks can help produce insights on SME-STI interactions with the potential to enable better innovation environments capable of affecting the regional development level.

The relevance of this approach lies in the fact that innovation projects developed by companies, at IUR interactions' scope, are the ones capable of enabling innovation in a given economy (Zhao; Li, 2022). Moreover, according to Brem and Radziwon (2017), several studies focus on investigating projects developed at the national/regional level, to the detriment of local projects. Universities are often placed as central actors in this process (Etzkowitz, 2002; Etzkowitz; Leydesdorff, 2000), whereas research institutes can also play the most relevant role in the system, according to Chen *et al.* (2020) and Zhang, Chen and Fu (2019). Finally, the Triple Helix-based approach was herein combined with Social Network Analysis, since there are few studies based on this perspective in the innovation field, mainly in developing - or even poorly developed - regions, as pointed out by Barrie, Zawdie and João (2019) and Chen and Lin (2017).

Thus, the aim of the current study was to help fill the aforementioned gaps in this research field by analyzing the performance of these institutional actors (in centrality terms) and the structural features of a network built at the local level.

INNOVATION NETWORKS AND REGIONAL DEVELOPMENT

The Triple Helix approach is used to help better understand innovation networks. This approach consists of a theoretical model capable of describing the foundations of innovation networks, based on the University-Industry-Government (UIG) relationship, with emphasis on the university, which is endowed with a potential key function in knowledge-based economies (Etzkowitz, 2002; Etzkowitz; Leydesdorff, 2000). The Triple Helix theory can be considered a generic and flexible approach used to investigate nonlinear relationships or innovation-promotion synergies (Galvao *et al*., 2019; Zhang; Chen; Fu, 2019). The initial focus of this theory lies on the UIG relationship; however, its derivations (Galvao *et al*., 2019) and use to support research involving IUR interactions in innovation (Barrie; Zawdie; João, 2019; Chen; Lin, 2017) and scientific collaboration fields (Chen *et al*., 2020; Zhang; Chen; Fu, 2019), in combination to network analysis, enable understanding IUR interactions in innovation projects.

Innovation Network's importance increases if one takes into consideration studies available in the literature about companies' need of promoting innovation processes (Angelini *et al.*, 2017; Edler; Fagerberg, 2017; Mazzucato; Semieniuk, 2017; Faccin; Balestrin; Bortolaso, 2016). According to Angelini *et al.* (2017), these networks are one of the key elements enabling the subvention policy's positive performance, mainly due to overflow effects resulting from the network structure.

Therefore, the network structure provides elements capable of contributing to the best interpretation of relationships established among actors, since it provides useful information for research, and policies, as well as for actors, themselves. Moreover, as evidenced by different authors (Awasthy *et al.*, 2020; Pereira *et al.*, 2018; Camera; Parente, 2017), establishing partnerships among IURs is a good strategy applied to innovation projects. The following assumption was herein elaborated: the government agency development policy for innovation projects helps structure innovation networks through IUR interactions. This assumption finds its theoretical background in authors, such as Brem and Radziwon (2017), Edler and Fagerberg (2017), Mahmoudzade and Alborzi (2017) and Mazzucato and Semieniuk (2017), whose studies have evidenced the important role played by the public promotion of innovation as an incentive mechanism to cooperation-networks formation in innovation processes involving industries and STIs.

In addition to encouraging innovation networks, mainly IUR collaboration networks, the aforementioned policy promotes regional development processes through these very same networks. Government policies should support innovation, as well as the formation of - and incentives to - networks, in a combined manner, since this combination helps promote regional development (Min; Kim; Sawng, 2020; Zhao; Li, 2022). In addition, the implementation of innovation incentive policies in less developed regions should be adopted as permanent practice (Ndabeni; Rogerson; Booyens, 2016) to systematically encourage collaborative projects between local companies and the academic field, from a network perspective.

From this perspective, although policy support remains in the process to be enhanced in less developed countries, as well as in the poorest regions within these countries, as observed in Brazil (Albuquerque *et al.*, 2015, Caliari; Rapini; Chiarini, 2020), public funding is more important in these countries than in developed ones, where private financing is much more relevant (Edquist, 2011, Ndabeni; Rogerson; Booyens, 2016). Thus, besides having political and financial support, it is essential to encourage interactions among actors involved in innovation processes.

The Triple Helix model supports the construction of relationships in the innovation system, which are used as strategic tools to promote development (Leydesdorff, 2012, Li *et al.*, 2018). Some of the main activities of the innovation system lie in encouraging interactions between innovative companies and other actors in the system, such as STIs, in order to integrate knowledge, as well as to develop a support policy that includes funding for innovation processes (Edquist, 2011). Based on the regional development approach, interactions taking place from the perspective of the aforementioned model appear to generate more benefits for SMEs in their local interactions (Li *et al.*, 2018).

IUR interactions in innovation projects promoted by regional policies provide several benefits that can have a positive impact on regional development processes, mainly in less developed regions experiencing a shortage of resources. Some of the overall advantages of these interactions comprise improved team skills; expanded access to human, financial and infrastructure resources (Faccin; Balestrin; Bortolaso, 2016; Parolin *et al.*, 2020); venture capital availability (Rojas; Huergo, 2016); as well as the interaction between companies and the academic field (Bellucci; Pennacchio; Zazzaro, 2019).

Both companies and STIs get benefits. More specifically, companies take advantage of access to researchers and research infrastructures, as well as to scientific support deriving from their bond to STIs (Chen; Lin, 2017; Parolin *et al.*, 2020), whereas STIs have the opportunity to show their work to the market and to society, as well as have the possibility of attracting new resources to related projects (Brem; Radziwon, 2017; Parolin *et al*., 2020). These advantages create an environment for innovation and development. However, some studies have also pointed out controversies about the benefits coming from this policy type, such as resource capture by interest groups (Rojas; Huergo, 2016), issues associated with property rights (Schütz *et al*., 2018) and lack of significant impact on companies' performance (Martinez-Covarrubias; Lenihan; Hart, 2017).

Several positive effects of IUR interactions are based on regional policy support. Support provided by regional and local institutions plays an important role in the process to build interactions among actors in innovation ecosystems (Leckel; Veilleux; Dana, 2020). One of innovation activities' main influences on companies and STIs comes from governmental programs, which provide subsidies for the development of innovation projects (Edquist, 2011). Companies, universities and other research organizations, as well as their interactions, are the factors both influencing and building innovation; thus, innovation policies should focus on relationships established among these actors, rather than just focusing on them (Edquist, 2011).

METHODOLOGY

OBJECT OF STUDY

Institutional partnerships steaming from innovation projects submitted to a government agency development program in the state of Ceará – i.e., the Technological Innovation Program (also known as Inovafit) by Support Foundation for Scientific and Technological Development of Ceará (also known as FUNCAP) - was the present object of study. Although the aforementioned program was implemented in 2015, it has been subjected to new editions every year. It aims at supporting (via economic subsidy) the implementation of innovation projects focused on companies whose annual revenues are lower than R$ 10 million (often classified as SMEs), in two independent phases, namely: a) Phase 1 lasts up to six months and comprises research about both the technical feasibility and

development of a minimum viable product (MVP), based on hiring projects whose value can reach up to R$ 100 thousand; b) Phase 2 lasts up to 24 months and aims at developing the innovation project, itself, starting from the presentation of a MVP and of a business plan for the new product, process or service, based on hiring projects whose value can reach up to R$ 400 thousand. It is worth emphasizing that companies participating in Phase 2 may, or may not, benefit from Phase 1, as well as that both phases require counterparts from companies of, at least, 10% of the project value.

DATA COLLECTION

Data were collected based on physical documental research conducted at FUNCAP's database and archives, between 2018 and 2019. Data about innovation projects submitted to the investigated program from 2015 to 2018 were analyzed. The number of projects analyzed per year and per program phase was recorded, as follows: 139, in 2015 - Phase 1; 100, in 2016 - Phase 2; 119, in 2017 - Phase 1; and 80, in 2018 - Phase 2.

Two databases were taken into consideration: one of them came from the network of submitted projects (NPSub) and the other one from selected projects (NPSel). Collected data comprising: a) Companies proposing innovation projects; and b) a set of partner actors in projects, divided into universities and research institutes, based on Chen *et al*. (2020) and Zhang, Chen and Fu (2019), and other organizations that could be non-proponent companies in the respective network, although they act in innovation, or in innovation support organizations, as defined by Edquist (2011).

Information about relationships among actors (institutional) was collected from innovation projects, as well as through consultations to the Lattes platform to help identify connections of team members. Attention was given to coincidences between bond and proposal submission periods in the Lattes platform. This procedure enabled drawing a prescribed network of institutional actors participating in innovation projects, similar to that conducted in other network studies, such as the ones by Franco, Câmara and Parente (2017) and Hernández and González (2017).

DATA ANALYSIS

The herein-conducted network analysis admitted two different matrices referring to innovation projects, namely: (a) the NPSub matrix, which encompassed all proposals with some established institutional relationship; and (b) the NPSel matrix, which only focused on proposals selected for funding purposes in the program. Relationships were considered bidirectional and weightless, based on Mahmoudzadeh and Alborzi (2017) and Zheng and Zhao (2013). These choices were based on the premise of exchange between actors (knowledge is not a one-way process) and on hard time weighing the participation of project team members. Furthermore, the option made for analyzing one broad and one refined network - NPSub and NPSel, respectively - rests on the attempt to perceive structural differences between them, since NPSub has the potential to be encouraged by presenting innovation projects to compete for the promotion of an innovation policy (more specifically, the Inovafit program), whereas NPSel is effectively promoted by this policy.

Relational matrices were assembled in Excel spreadsheets and analyzed in Gephi software to get statistics and network graphs. The obtained connection networks were defined as full networks (Wasserman; Faust, 1994), because they presented relational configurations within a limited group – in this case, projects proposed in the development program. According to Hâncean, Molina and Lubbers (2016), one can use metrics of properties of the entire network (network level), of structural positions of each actor in the network (actor level), as well as of groups of actors (meso level), to analyze this network type.

Thus, the following metrics of the network's structural level were calculated (Cherven, 2015; Wasserman; Faust, 1994): (a) density - it indicates the intensity of connections among actors; (b) average degree - it expresses the mean number of connections per actor; (c) diameter – it represents the network's linear size; and (d) average path length - it defines the shortest mean path between two network actors. The following actors' centrality position metrics were also measured (Freeman, 1979): (a) degree - it provides the number of connections of each actor; (b) betweenness - it represents the links in the connection among different pairs of actors; and (c) closeness - it measures the mean distance of a specific actor from the others. These metrics were selected because, according to Muller and Peres (2019), they are often used in studies conducted in the innovation field and summarize

how central the role played by a given actor can be. Finally, metrics associated with groups were used (Cherven, 2015; Wasserman; Faust, 1994), namely: (a) connected components - they indicate the existence of physically separated groups; (b) modularity - it reflects the bond of a set of actors based on shared features; and (c) average clustering coefficient - it represents the likelihood of a pair of actors linked to a third actor to be also connected. According to Cherven (2015), these group metrics synthesize the first two levels of measurement when they show how actors in these groups work to model the network's internal structure.

NETWORK ANALYSIS APPLIED TO INNOVATION PROJECTS BASED ON IUR INTERACTIONS

This section presents the analysis applied to networks, based on calculated metrics and on graphs plotted for the investigated period (2015-2018). It was done to help better understand the role played by both actors and categories of actors in IUR interactions within the Triple Helix structure.

NETWORK STRUCTURE METRICS OF IUR INTERACTIONS

Initially, it was possible noticing that NPSel had a smaller number of actors and connections than NPSub throughout the analyzed period. It happened because NPSel was only formed by projects selected for development purposes. In addition, networks formed in 2015 and 2017 presented more actors and connections, likely because they refer to the programs' Phase 1, which presented a larger number of proposing companies and lower project value (and, consequently, lower counterpart) than those observed for Phase 2, as well as because it did not require MVP.

As shown in Table 1, because NPSel was a smaller network, it was also less dispersed and recorded higher density rates (approximately three times higher than that of NPSub), which reached approximately 10% and 11% in 2016 and 2018, respectively. These density values can be accepted as median if one takes into consideration other studies about innovation networks; they were close to values recorded by Franco, Câmara and Parente (2017) and Hernández and González (2017), much higher than density of 0.002 (Pereira *et al.*, 2018) and well below values of approximately 30% (Barrie; Zawdie; João, 2019; Machado; Ipiranga, 2013). This is a relevant indicator

because the transfer and distribution rates of resources, such as knowledge, increase in denser networks - as for the current case, in NPSel -, mainly in Phase 2 of the investigated program. However, according to Zhao and Li (2022), density must have a reasonable range, since quite dense networks are not desired because actors, mainly companies, have a limit to establish interactions and they should not blindly seek partnerships for their innovation projects.

Table 1 | Network structure metrics extracted from networks of projects submitted (NPSub) and selected (NPSel) from 2015 to 2018.

Metrics	2015 - Phase 1		2016 - Phase 2		2017 - Phase 1		2018 - Phase 2	
	NPSub	NPSel	NPSub	NPSel	NPSub	NPSel	NPSub	NPSel
Actors	218	105	186	77	216	79	155	60
Links	640	359	631	279	627	226	421	199
Density	0.027	0.066	0.037	0.095	0.027	0.073	0.035	0.112
Average degree	5.872	6.838	6.785	7.247	5.806	5.722	5.432	6.633
Network diameter	6	5	5	4	5	4	5	3
Average path length	2.505	2.250	2.483	2.141	2.482	2.234	2.351	2.102
Components	4	1	1	1	3	2	6	1
Modularity[1]	0.475	0.428	0.488	0.428	0.505	0.451	0.493	0.414
Communities[1]	11	8	11	7	11	8	13	5
Average clustering coefficient	0.790	0.768	0.785	0.773	0.839	0.781	0.856	0.805

Source: elaborated by the authors. Note: 1the standard modularity detection algorithm with resolution 1.0 was used in Gephi software to avoid generating either many communities with few actors or few communities with many actors.

Average degree values, in their turn, were often higher in NPSel; they also tended to increase throughout the investigated period, as well as within each cycle (Phase 1 - Phase 2). The herein-measured values (ranging from 5.432 to 7.247) were higher than those recorded by other studies (Cunha *et al.*, 2016; Pereira *et al.,* 2018); they indicated a relevant mean number of connections per actor. There was a close correlation between density and average degree values (Muller; Peres, 2019), as well as a slightly positive correlation between them in the analyzed networks; this finding suggested that the network gets more diffuse as actors increase their mean number of contacts. This movement can be beneficial to a certain point; after that, knowledge flow can become redundant

(Mahmoudzadeh; Alborzi, 2017; Zhao; Li, 2022; Zheng; Zhao, 2013) and fail significantly improve regional innovation performance.

The investigated networks have also shown low diameter, and it indicated the number of steps necessary for knowledge to cross the entire network; this number was always smaller in NPSel, due to its smaller size. In this case, the calculated diameters may have evidenced a non-compact network (Cherven, 2015), with values close to, and lower than, those calculated by Hernández and González (2017) and Pereira *et al*. (2018), respectively.

Overall, structural configurations in different networks did not indicate high density or the need for a large crossing over the network, although they pointed towards a reasonable mean number of connections. This factor contributed to many actors interacting from short average path lengths (distances), as well as enabled each actor to access others in a few steps (ranging from 2.1 to 2.5), a fact that evidenced some communication and network performance efficiency (Angelini *et al*., 2017; Chen *et al*., 2020; Cherven, 2015). According to Chen *et al.* (2020), the larger the number of actors and the shorter the distance between them, the more benefits are generated in the network. Distances measured in the current study were similar to those recorded by Cunha *et al.* (2016).

Concerning clustering measures, modularity was directly correlated to the number of communities; there was a strong positive correlation between them. Communities' detection results from an optimization process and it means making the emergence of densely connected groups of actors explicit by maintaining sparser connections with actors from other groups (Newman, 2006). The herein calculated modularity coefficients have indicated a reasonable number of communities, mainly in NPSub.

It was possible observing a scenario of one, or more, adjacent micro-components (four actors, at most) close to the macro component, even when more than one component was observed, mainly in NPSub. The existence of a few components, or macro components, is also an indication of greater connectivity in the network. Pereira *et al.* (2018) observed hundreds of components, whereas Chen and Lin (2017) and Franco, Câmara and Parente (2017) found dozens of them, as indications of low connectivity in their research.

The clustering coefficient consists of the mean of individual values and indicates proximity to the potential of triad relationships in the network. The herein recorded values have indicated that actors used from 77% to 86% connections available in the neighbourhood, or that four of every five likely triangles in the network were formed, on average, and it indicated a high clustering rate. Cunha et al. (2016), for example, have calculated much lower values, which ranged from 9% to 43%. NPSub and the second cycle of the program (2017-2018) always recorded the highest clustering coefficient. This metric provides two analysis perspectives, according to Muller and Peres (2019): on the one hand, a larger cluster allows a given actor to have better chances of exchanging knowledge with other actors in the group, as well as increasing the knowledge flow. However, this factor can make the knowledge exchanged in the group more redundant, due to several neighbourhood connections.

After the assessment of different structural metrics was over, the current study analyzed centrality metrics of institutional actors and network graphs. The investigated networks presented hubs that made the networks more connected to each other, as shown below (Muller; Peres, 2019). Thus, without the strong presence of these hubs in the development program, many of the metrics seen so far would likely show lower performance, such as smaller density, average degree and clustering coefficient or larger diameter and longer average path length.

INSTITUTIONAL ACTORS' DEGREE CENTRALITY

Based on the analysis of degree-centrality metrics, it was possible identifying an actor-positioning pattern, according to which, universities took the most central roles, and it is in compliance with other studies about innovation networks, such as Chen and Lin (2017), Pereira et al. (2018), Franco, Câmara and Parente (2017) and Machado and Ipiranga (2013). The four main universities in state of Ceará stood out, namely: Federal University of Ceará (UFC - Universidade Federal do Ceará), Federal Institute of Education, Science and Technology of Ceará (IFCE - Instituto Federal de Educação, Ciência e Tecnologia do Ceará), state of Ceará University (UECE - Universidade Estadual do Ceará) and University of Fortaleza (UNIFOR - Universidade de Fortaleza). However, this coordination power decreased over time, although these institutions still have considerable influence levels in comparison to that of other actors. This quartet was mainly followed by research institutes, such as the National

Service for Industrial Learning (SENAI - Serviço Nacional de Aprendizagem Industrial), the Brazilian Agricultural Research Corporation (EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária), the Information and Communication Technology Institute (ITIC - Instituto de Tecnologia da Informação e Comunicação) and the Latin American Center for Innovation, Excellence and Quality (CLAEQ - Centro Latino Americano para Inovacao, Excelencia e Qualidade), as well as by some secondary universities, in addition to the Brazilian Micro and Small Business Support Service (SEBRAE - Serviço Brasileiro de Apoio às Micro e Pequenas Empresas), which is an innovation support organization pointed out by Edquist (2011) as consulting organization for services focused on promoting innovation processes.

It was possible seeing that no company appeared among the most connected ones in the first cycle of the program (2015-2016), unlike what happened in the second cycle (2017-2018) of it, when some companies stood out in the top 10 most central ones. This fact could be associated with the establishment of greater connectivity by the proposing companies but, in fact, it is linked to centrality loss by the most central actors.

Table 2 presents the highest degree-centrality metrics observed for the first and last investigated years. Overall, universities presented a more competitive performance, mainly due to the broad presence of the UFC, UECE, UNIFOR and IFCE quartet, and, according to Chen and Lin (2017), due to their high research capacity. UFC's firm position at the top of the centrality ranking can be seen throughout the investigated period, in NPSel, except for 2018, when UNIFOR, UECE and IFCE were more competitive - mainly IFCE, which had the strongest influence on the network. The behaviour of these three universities can be explained by their bond to companies that recorded the best performance in the program's selection process and that relatively lost fewer connections in the transition from NPSub to NPSel.

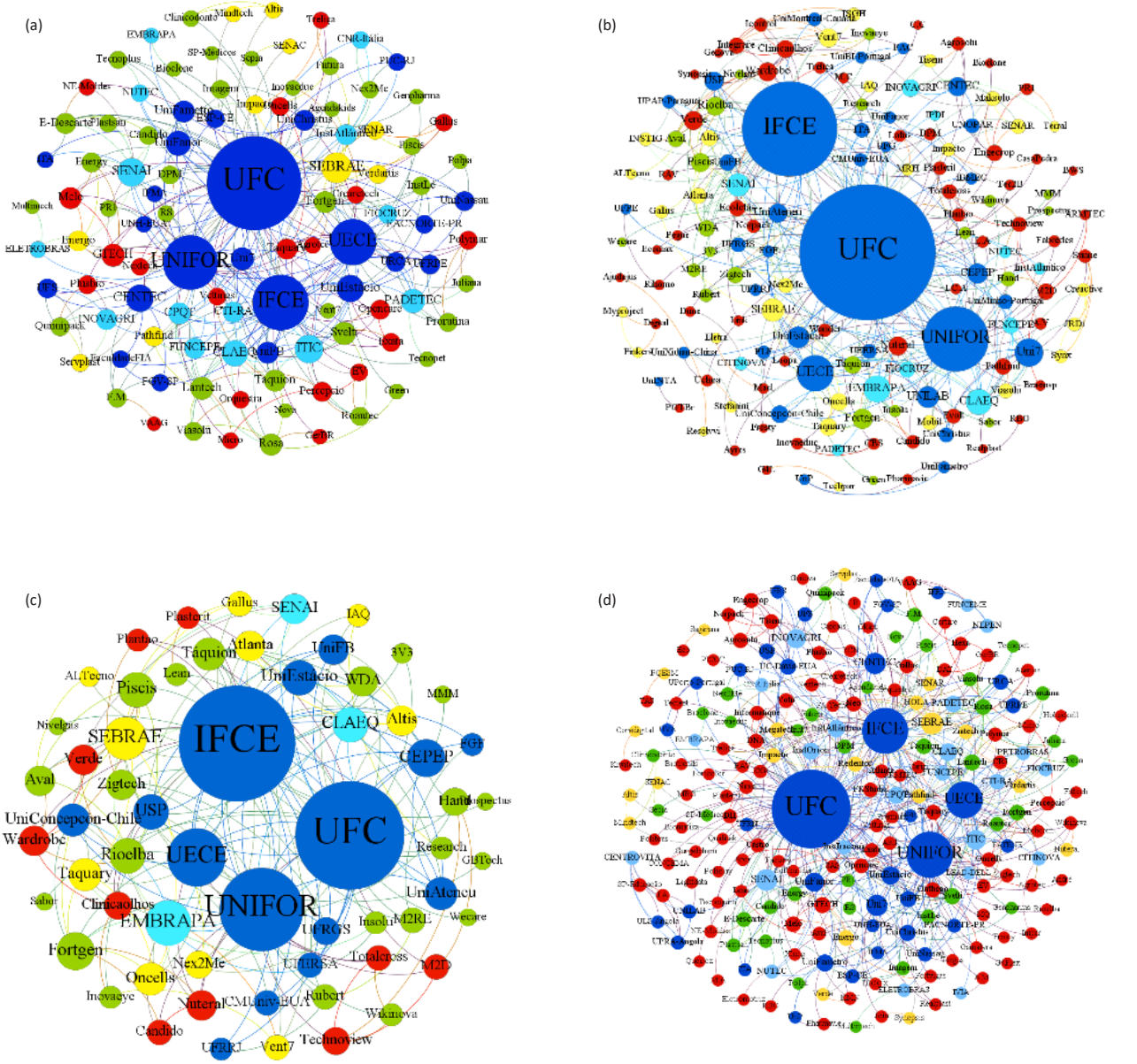
Table 2 | Ten highest actor-degree centrality metrics of the network of projects submitted (NPSub) and selected (NPSel) in 2015 and 2018.

2015 - Phase 1				2018 - Phase 2			
NPSub		NPSel		NPSub		NPSel	
UFC	130	UFC	76	UFC	94	IFCE	40
IFCE	67	IFCE	40	IFCE	64	UFC	37
UNIFOR	67	UNIFOR	39	UNIFOR	42	UNIFOR	27
UECE	49	UECE	31	UECE	21	UECE	17
SEBRAE(O)	20	SEBRAE(O)	16	Uni7	15	EMBRAPA(RI)	12
SENAI(RI)	20	ITIC(RI)	14	EMBRAPA(RI)	14	SEBRAE(O)	11
CENTEC	19	SENAI(IP)	14	CLAEQ(RI)	13	CEPEP	9
Uni7	19	UniEstácio	13	SEBRAE(O)	11	Fortgen(S)	9
ITIC(RI)	16	CENTEC	13	SENAI(RI)	11	CLAEQ(RI)	8
INOVAGRI(RI)	15	CLAEQ(RI)	12	UNILAB	10	USP	8

Source: elaborated by the authors. Notes: All actors are universities, except for (RI) research institutes, (S) selected companies, and (O) other organizations.

It is worth pointing out some research institutes, such as SENAI, EMBRAPA, ITIC and CLAEQ, which also showed increased competitiveness in the transition from NPSub to NPSel, over the investigated period, by establishing links to companies holding selected projects. SEBRAE (the 'other organizations' category) also stood out for its significant centrality in virtually all investigated years. Several other universities appeared in both networks, although at a secondary level and with lower interconnection influence; most of them were private universities and some of them were located in other Brazilian states and abroad (it likely happened because members of the project teams were attending master's and doctoral studies or were in postdoctoral internship). Figure 1 presents the visual representation of the degree of centrality observed for all actors in all networks, in the first and last investigated years.

Figure 1 | Networks of submitted (NPSub) and selected (NPSel) projects, based on degree centrality and the category of actors.



Source: elaborated by the authors. Notes: Node colour designates institutional actor categories (blue = universities; light blue = research institute; green = selected company; red = non-selected company; yellow = other organizations), whereas node size designates degree centrality. Networks of projects submitted (a) and selected (b) in 2015, as well as submitted (c) and selected (d) in 2018.

The relative number of connections established in NPSel, in comparison to NPSub, provides the competitiveness level of actors' categories in terms of selected project teams' composition. If one takes into consideration the entire investigated period, universities and research institutes recorded slightly increased participation in relative terms, on average, when they transitioned from NPSub to NPSel; they recorded higher competitiveness rates, whereas other organizations have shown a small reduction in them. However, if one only takes into consideration the frequency of actors' categories in NPSel, there was an intense reduction (relative and absolute) in research institutes' participation, if one compares values recorded for 2018 to the ones observed for 2015. On the other hand, universities have shown a slight increase in their relative frequency, as well as they decrease in absolute number, although to a lesser extent; this finding suggested that the aforementioned reduction only referred to the decreased number of actors in the network (as shown in Table 1). Furthermore, it was possible pointing out the relative growth of, and stabilization (in absolute terms) in, the participation of the category "other organizations".

Non-selected companies were quite frequent in NPSel due to their connections to selected companies. This finding has indicated a network involving partnerships between several proposing companies, and it is a relevant feature of the investigated network. Non-selected companies accounted for 1/3 to 1/2 of the total number of companies (selected and non-selected) forming NPSel. On the other hand, from 1/2 to 2/3 of selected companies had links to other companies participating in the network (selected companies, non-selected companies or those included in the category "other organizations". This is a good indicator, since networks of cooperation between companies also influence the construction of innovative abilities, as suggested by studies about innovation networks (Franco; Câmara; Parente, 2017; Hernández; González, 2017; Zheng; Zhao, 2013).

The highest centrality observed for the Influential quartet of universities has indicated that they may see themselves, and be seen, as important knowledge flow channels in the network (Freeman, 1979). Thus, one can expect a more practical training process, as well as the expansion of links outside the academic environment – it would indicate greater university-market adherence (Franco; Câmara; Parente, 2017) -, in addition to an increase in the number of new research funding opportunities and relationships (Brem; Radziwon, 2017). These are some of the adjacent goals of

innovation promotion programs, such as the one investigated in the current study.

All selected companies in NPSel have maintained ties with universities or research institutes for the entire investigated period. Therefore, the perception that the strategy of building links between companies and STIs seems to have some effect was herein reinforced. The analysis applied to the metrics and the degree centrality graphs of the networks at development program scope have suggested high connectivity among hubs, whose pattern was similar to the structure of scale-free networks (Barabási, 2009; Barabási; Albert, 1999), wherein four universities presented a large number of connections, whereas a large number of actors presented few connections.

Universities played a central role in the process to develop innovation in partnership with companies, since the results of IUR interactions with innovation projects quickly reached society, unlike what often happens with research limited to the academic field, such as basic research (Zhao; Li, 2022). Therefore, the IUR interactions' effects on less developed regions can be amplified by adopting a specific policy to encourage SME projects.

BETWEENNESS, CLOSENESS AND MODULARITY CLASSES

Concerning the analysis applied to betweenness centralities, it is worth emphasizing that the greater the power of a given institution to intermediate connections, the more important its role in the network, since it has greater control (facilitating or limiting) of knowledge flows in the network (Cherven, 2015; Freeman, 1979; Wasserman; Faust, 1994). The presence of a given actor as an intermediary agent is measured as the frequency of its emergence on the shortest paths between other actors in the network. Betweenness statistics observed for the first and last investigated year are shown in Table 3, which indicates that UFC, IFCE, UNIFOR and UECE were more capable of intermediating connections, as well as stood out for playing the role of knowledge flow bridge in the network.

Table 3 | Ten highest actors' betweenness centrality metrics of the network of projects submitted (NPSub) and selected (NPSel) in 2015 and 2018.

2015 – Phase 1				2018 – Phase 2			
NPSub		NPSel		NPSub		NPSel	
UFC	0.565	UFC	0.566	UFC	0.537	IFCE	0.400
IFCE	0.188	IFCE	0.186	IFCE	0.247	UFC	0.351
UNIFOR	0.187	UNIFOR	0.137	UNIFOR	0.144	UNIFOR	0.185
UECE	0.092	UECE	0.101	Uni7	0.059	UECE	0.081
UNILAB	0.044	CENTEC	0.041	UECE	0.044	SEBRAE(O)	0.029
Uni7	0.036	SEBRAE(O)	0.029	INOVAGRI(RI)	0.029	EMBRAPA(RI)	0.025
CENTEC	0.032	F.M(S)	0.019	CLAEQ(RI)	0.018	Rioelba(S)	0.017
SENAI(RI)	0.029	ELETROBRAS(RI)	0.019	SENAI(RI)	0.012	USP	0.007
UniFametro	0.028	SENAI(RI)	0.018	UniAteneu	0.012	SENAI(RI)	0.006
INOVAGRI(RI)	0.024	PADETEC(RI)	0.016	EMBRAPA(RI)	0.012	Nuteral(NS)	0.005

Source: elaborated by the authors. Notes: All actors are universities, except for (RI) research institutes, (S) selected companies, (NS) non-selected companies, and (O) other organizations.

UFC has shown strong performance in intermediating contacts in networks; it recorded metric value three to four times higher than the second best-positioned university, except for NPSel, in 2018, when IFCE recorded significant competitiveness gain. Unlike what was observed for degree centrality, more companies appeared in the top 10 betweenness ranking, although they recorded low statistic values. In other words, despite the constant presence of companies, their coefficients were very low, and it made their intermediation power in the network ineffective.

In short, universities were the institutions with the greatest power to mediate knowledge flows between actors in the investigated networks; this outcome was also recorded by Barrie, Zawdie and João (2019), Chen and Lin (2017), Franco, Câmara and Parente (2017), Machado and Ipiranga (2013) and Pereira *et al.* (2018). The aforementioned authors have also reported that companies played an important role in intermediating connections, unlike results in the current research, although some of them appeared in the top 10 ranking and even expressed the power of a superior link to many universities and research institutes.

Based on the analysis applied to closeness metrics, it was possible noticing that the closer a given institution was to other actors in the network, the greater the evidence of its central

position in it and the more relevant its power of reach and its role in knowledge sharing (Cherven, 2015; Freeman, 1979; Wasserman; Faust, 1994).

The highest closeness values recorded in the networks, for the first and last investigated year, are shown in Table 4. It is possible seeing a smaller amplitude between coefficient values recorded for the actors, in comparison to variations in degree and betweenness values. This finding has indicated greater equalization among different actors of the development program network since several actors with low relevance in connections and intermediation processes presented proximity levels close to that observed for the most strategic actors – i.e., universities and research institutes. Degree and closeness centralities, analyzed together, suggested that many of these actors established few connections, although with actors relatively well connected in the development program networks, mainly with the four main universities.

Table 4 | Ten highest closeness centrality values recorded for actors belonging to the networks of projects submitted (NPSub) and selected (NPSel) in 2015 and 2018.

2015–- Phase 1				2018–- Phase 2			
NPSub		NPSel		NPSub		NPSel	
UFC	0.708	UFC	0.776	UFC	0.746	IFCE	0.756
IFCE	0.575	IFCE	0.615	IFCE	0.624	UFC	0.728
UNIFOR	0.570	UNIFOR	0.612	UNIFOR	0.569	UNIFOR	0.648
UECE	0.528	UECE	0.575	UECE	0.524	UECE	0.584
SEBRAE(O)	0.492	SEBRAE(O)	0.533	CLAEQ(RI)	0.518	CEPEP	0.541
ITIC(RI)	0.490	ITIC(RI)	0.523	UniEstácio	0.504	UniEstácio	0.536
CENTEC	0.488	UniEstácio	0.520	CEPEP	0.502	CLAEQ(RI)	0.536
Uni7	0.487	CLAEQ(RI)	0.517	Rioelba(S)	0.495	SEBRAE(O)	0.532
SENAI(RI)	0.486	CENTEC	0.515	Zigtech(S)	0.492	Rioelba(S)	0.532
UniEstácio	0.486	SENAI(RI)	0.512	UFRGS	0.490	Zigtech(S)	0.522

Source: elaborated by the authors. Notes: All actors are universities, except for (RI) research institutes, (S) selected companies, (NS) non-selected companies, and (O) other organizations.

However, there was the consolidation of the main universities (UFC, IFCE, UNIFOR and UECE) in the best-reach positions. UFC remained in the first position for almost the entire period; it only lost its position to IFCE, in RPSel, in 2018. Research institutes, such as ITIC, CLAEQ, EMBRAPA and SENAI, recorded a significant presence in this ranking for several years. On the other hand, SEBRAE stood out in the reach of actors in the network, as well as repeated its competitiveness gain in terms of degree and betweenness, in NPSel. In addition, several companies, both selected and non-selected ones, had a power of reach equivalent to, or even higher than, that of many secondary universities and research institutes. The herein-observed greater emphasis on the proximity of universities participating in the investigated networks corroborated the study by Chen and Lin (2017), Franco, Câmara and Parente (2017) and Pereira *et al*. (2018). UFC, IFCE, UNIFOR and UECE held a more strategic position in the networks, and they indicated higher frequency in positioning themselves in the shortest path between any two other actors in the network (Cherven, 2015).

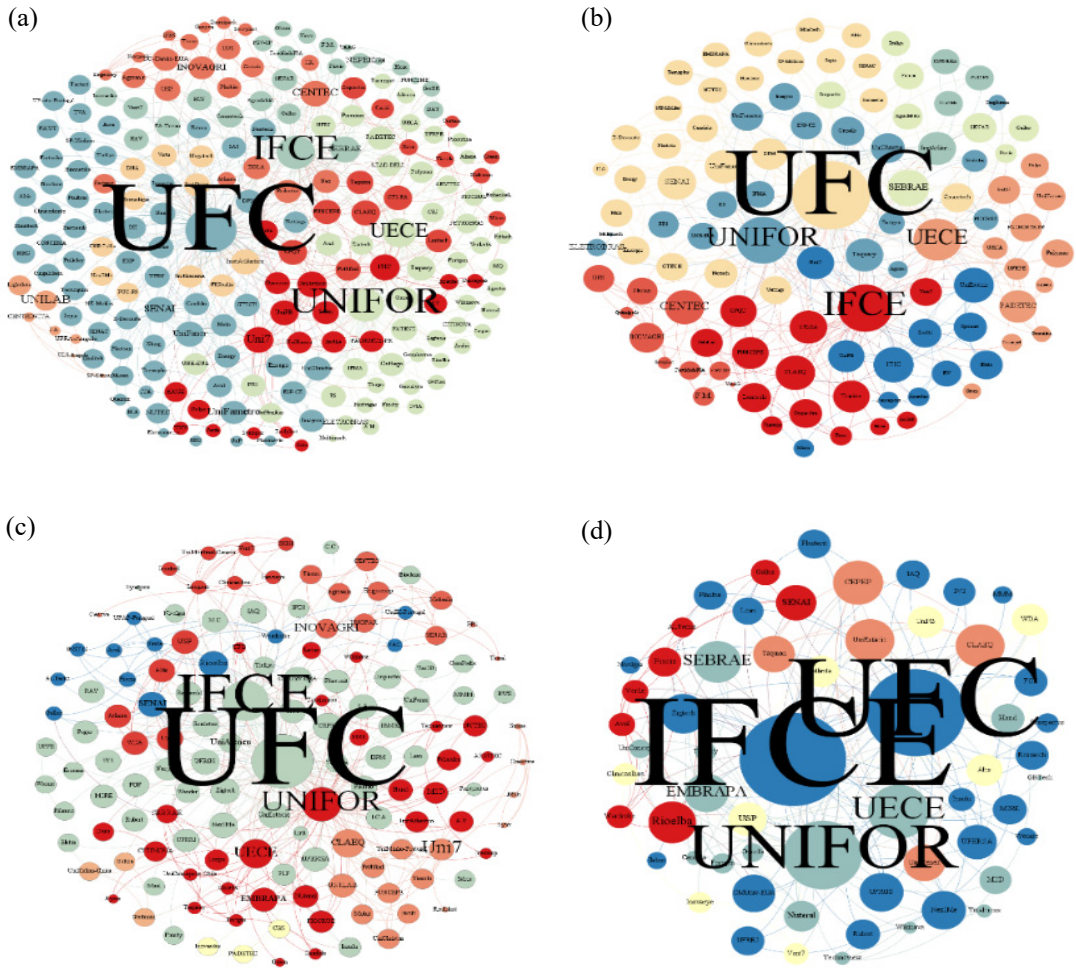
Overall, universities were the most powerful institutions in all measured centrality values. The reputation of this category of institutional actors appeared to generate a preferential attachment (Barabási, 2009; Barabási; Albert, 1999; Mahmoudzadeh; Alborzi, 2017) on the part of proponent companies in the development program, and it resulted in more ties (degree), in greater flow control (betweenness) and in greater reach (closeness) in the network by the four main universities – network hubs. According to findings by Mahmoudzadeh and Alborzi (2017), this movement resulted in a scale-free structure in the nanotechnology network, in Iran. Moreover, according to Cherven (2015), this correlation – higher degree, great mediation and high reach – may depend on network structure, and it is more likely to take place in high-clustering networks.

The current research has found evidence that the network formed in the program has evidenced a positive correlation between centrality metrics and a high average clustering coefficient. This finding also indicated a scale-free structure because, as suggested by Barabási and Bonabeau (2003), high-clustering networks may be indicative of this structure type. Therefore, it is plausible to say that this combination makes the existence of scale-free networks feasible. This condition emphasizes the existence of hubs (four universities) and it makes the networks more connected, as evidenced by the high clustering coefficient and by the short average path distance (Muller; Peres,

2019). This denser clustering with the presence of hubs can also lead to greater knowledge redundancy in the network and concentrate resources on the hand of a few actors, thus reducing the network's innovation capacity (Mahmoudzadeh; Alborzi, 2017; Zheng; Zhao, 2013). Greater redundancy may be credible in the case of the herein analyzed network, but the concentration of resources is hardly credible, since companies are the ones that get financed, whereas the hubs are cooperative actors in innovation projects. The scale-free structure of the analyzed networks enables greater knowledge outspread due to the hubs' connection strengths, and it can provide better infrastructure for growth and non-discriminatory outspread of innovative knowledge in the network (Angelin *et al.*, 2017). The scale-free mechanism observed in the IUR interaction network has evidenced that companies significantly depended on four universities, and it may imply some limitations to the volume of generated innovation, due to redundancy. On the other hand, it also suggested greater distribution and higher speed of knowledge generated in the network.

Figure 2 exposes the network influence in intermediating relationships, its ability to reach actors and the formation of more similar communities, in the first and last investigated years. Over the investigated period, UNIFOR and UECE recorded a higher trend to compose the same community in NPSub. This trend was more evident in the last cycle (2017-2018) when this affinity was also observed in NPSel. This similarity may have its origin in the greater focus that both universities placed on the biotechnology field since they often participated in projects developed in it.

Figure 2 | Networks of Project submitted (NPSub) and selected (NPSel) based on modularity classes, as well as on betweenness and closeness centralities.



Source: elaborated by the authors. Notes: Node colour designates communities, node label size designates betweenness centrality, and node size designates closeness centrality. Networks of projects submitted (a) and selected (b) in 2015, as well as submitted (c) and selected (d) in 2018. The standard modularity detection algorithm with resolution 1.0 was used in Gephi software to avoid generating many communities with few actors or a few communities with many actors.

UFC and IFCE formed different communities throughout the investigated period, in both networks, except for 2018. The great diversity of UFC's activity fields, such as health, biotechnology, civil construction, water resources, materials engineering, agribusiness, food industry, and information and communication technology – ICT, may likely contrast with IFCE's greater specialization in ICT and electromechanics fields. However, both universities have formed a consistent community, with a smaller network, in the last investigated year.

It is also worth emphasizing that these four universities have aggregated many research institutes in their groups throughout the entire investigated period; some of them have even formed separate communities at different times. In 2015, the Institute for Research and Innovation in Irrigated Agriculture (INOVAGRI - Instituto de Pesquisa e Inovação na Agricultura Irrigada), CLAEQ and ITIC formed separate communities in NPSub, whereas INOVAGRI and ITIC have formed separate communities in NPSel, with emphasis on a group formed by SEBRAE - which is representative of category 'other organizations' - in this network. In 2016, SENAI, INOVAGRI, ITIC and Technological Development Park (PADETEC - Parque de Desenvolvimento Tecnológico) formed separate communities in NPSub; each of these institutions, except for PADETEC, focused on a specific field, such as electrometalmechanics, water resources, health, biotechnology and ICT. On the other hand, PADETEC stood out in NPSel for maintaining a group operating in ICT, health and biotechnology; whereas ITIC stood out for forming a larger group, together with CLAEQ, in the ICT field. In 2017, the ITIC, SENAI and PADETEC triad jointly led a large group in NPSub, INOVAGRI led a smaller group in it, and ITIC led a community in NPSel. On the other hand, in 2018, SENAI, CLAEQ and INOVAGRI were the leaders of separate groups and showed significant consistency, since the network was smaller.

Since modular classes enable identifying groups of actors by sharing connective features in the network as a whole (Cherven, 2015), and it suggests community composition is strongly connected to a given group and establishes a more dispersed connection to actors from other groups (Newman, 2006), communities stronger than others may be oftentimes evidenced for grouping the most central actors. It is clear that the four main universities lead communities in different networks - sometimes separate, sometimes in partnership with peers -, as well as that several research institutes also form their groups with high connective similarity, either separate or in partnership with their peers.

Concerning the formation process of modularity classes, studies focused on investigating this structure in the network contribute to highlighting groups of actors who preserve more affinities among themselves. Classes defined in this research were considered credible, even if - as pointed out by Newman (2006) - there is the possibility of a poor network division by

communication structure methods. Based on the analyzed results, the four main universities have shown more vigour in the central role played by them in the network; moreover, they showed greater affinity to share relational features, whereas research institutes presented a higher trend to form separate groups, mainly in NPSel.

Briefly speaking, several policies to support innovation, mainly in less developed regions, have been implemented by local public programs, whereas regional governments play a central role in subsidizing local companies' innovation (Bellucci; Pennacchio; Zazzaro, 2019). These programs play a key role in encouraging either the development or the creation of IUR interaction networks, and it echoes regional innovation by companies (Min; Kim; Sawng, 2020; Ndabeni, Rogerson & Booyens, 2016; Zhao; Li, 2022). In fact, an innovation network, such as the one herein featured by IUR interactions and subsidized by a governmental program, can contribute to improving the regional innovation environment, and it reflects on regional development.

FINAL CONSIDERATIONS

The current research has evidenced features and addressed implications based on the analysis applied to a network formed within the program aimed at promoting SME innovation projects for four years (2015-2018). The analysis applied to social networks of IUR interactions enabled observing the configuration of features associated with the relationship between institutional actors, according to which, network structure and centrality metrics presented different behaviours, depending on the comparison between NPSub and NPSel networks, and between Phases 1 and 2 of the investigated program. Increased cluster density, average degree and average clustering coefficient values were observed during the assessed period, as well as a fine reduction in modularity and average path length. Moreover, it was possible noticing different numbers of communities in each network, reduced network diameter and increased number of connected components.

The herein conducted analysis has indicated high centrality of universities, notably the most important universities of the state of Ceará (UFC, IFCE, UECE and UNIFOR), which act as hubs in the network. These universities were the most central institutions in degree centrality, betweenness and closeness measurements. This institutional category was the one holding more control and

greater power in the innovation network; it was followed by research institutes.

Networks formed at governmental agency program scope were not random and significantly expressed several properties of networks with scale-free structure. The aforementioned networks were highly clustered and presented average degree and distribution following the law of power, as well as evidenced hubs presenting special centrality, which indicated the scale-free mechanism. In fact, these indicative results have suggested that companies are quite dependent on hubs (four universities) in IUR interactions, as well as that industries' relationship with research institutes is comparatively weaker. Therefore, they enable the continuous concentration of power under the control of a few actors who played the role of hub, as well as the possibility of higher redundant knowledge flow, although with higher speed in this flow and broader access to companies forming the network. Thus, based on research findings, it is possible to state that the research question was answered when network structure, institutional actors' positioning in the analyzed project networks and the implications of this configuration were featured.

The herein investigated program helps encourage IUR interactions and create an innovation network. Involvement in collaborative innovation activities, such as the IUR network, is one of the relevant factors promoting innovation activities in companies. Moreover, public subsidy to local businesses' innovation, such as the investigated INOVAFIT development program, is also an incentive factor for innovation, mainly in SMEs. From the regional development perspective, cooperation networks are oftentimes encouraged by governmental policy support, and it enables cooperation between SME entrepreneurs and researchers from universities and research institutes. This dynamics helps improve the innovation environment.

Contributions from the current research can be summarized into three points. Firstly, it contributes to the scarce number of empirical studies focused on analyzing networks in innovation projects proposed by SMEs and fostered by governmental programs, with emphasis on local-level projects and on differentiating the analysis applied to projects submitted to (potential network) and selected (real network) by the investigated program. Secondly, it differentiates the degree of importance held by universities and research institutes in the networks. Thirdly, it combines the approach based on the Triple Helix method from the Social Network Analysis perspective.

Despite the aforementioned contributions, the current study also presents some limitations, such as a lack of analysis applied to financial resources directed to target companies and markets, with emphasis on institutions that kept partnerships with benefited companies. In addition, because the herein conducted analysis used documental data, networks' visualization took place in prescribed groups, and it may differ from that of group networks emerging during the implementation of innovation projects.

Studies focused on investigating the effects generated by the development policy on the innovation network within the analyzed program should be conducted to help broaden the understanding of this topic. It is so because these results are often affected by the network structuring type, where one can see the low effectiveness of the policy in scale-free structures, the presence of hubs and the likely generation of positive effects on less centralized networks. If future studies indicate the ineffectiveness of this policy, this finding would be another factor corroborating the herein-addressed scale-free structure.

Acknowledgement: The authors are grateful to FUNCAP for granting access to the assessed files and for supporting the current research.

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