

MUTUALISM IN ECOSYSTEMS OF INNOVATION AND ENTREPRENEURSHIP: A BIDIRECTIONAL PERSPECTIVE ON UNIVERSITIES' LINKAGES

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ACKNOWLEDGEMENTS

The authors acknowledge funding from the São Paulo Research Foundation (Fapesp Grant #2016/17801-4). Bruno Fischer's contribution to this article is based on the study funded by the Basic Research Program of the National Research University Higher School of Economics (HSE) and by the Russian Academic Excellence Project '5-100'. Paola Schaeffer's contribution to this article is based on the study financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. The authors thank Espaço da Escrita – Pró-Reitoria de Pesquisa - UNICAMP - for the language services provided.

Suggested citation:

Schaeffer, P.R., Guerrero, M., Fischer, B.B. (2021). Mutualism in ecosystems of innovation and entrepreneurship: A bidirectional perspective on universities' linkages. *Journal of Business Research*. Volume 134, September 2021, Pages 184-197. <https://doi.org/10.1016/j.jbusres.2021.05.039>

ABSTRACT

The accumulation of knowledge that explains universities' contributions to innovation and entrepreneurship's regional eco-systems has mainly adopted a perspective based on technology transfer processes from academia to markets. In this study, we assume the notion of mutualism, based on the biomimetic rationale of eco-system studies that involve bidirectional flows of resources and capabilities to generate interactions and value co-creation among agents. This study theorizes about the interrelation between universities and eco-system actors in two directions: (a) universities fostering and improving eco-systems through their core activities; and (b) eco-system actors shaping capabilities and access to resources for universities. Based on the analysis of five eco-systems in the state of São Paulo, Brazil, our results underscore the existence of mutualism in the relationships established between universities and eco-system agents. The findings also highlighted implications related to the coordination of policies and the need for strategic management practices in mutualistic interactions.

KEYWORDS

Entrepreneurial Universities; Innovation Eco-systems; Entrepreneurship Eco-systems; Bidirectional relationships; University-Industry Collaboration; Emerging Countries

HIGHLIGHTS

1. University-industry mutualism re-configures the eco-systems actors and impacts.
2. University-industry mutualism enhances the eco-systems innovative/entrepreneurial culture.
3. Eco-systems mutualism reinforces university-industry collaborations and impacts.
4. Mutualism needs well-organized managerial university structures.
5. Mutualism requires coordination of regulations at different geographical scales.

1 INTRODUCTION

Over the last decade, the literature has contributed to a better understanding of the inputs and outputs of entrepreneurial universities (Romero et al., 2020). Universities are organizations that generate human capital and knowledge and diffuse them by establishing interactions with multiple actors that promote regional development (Guerrero et al., 2015; Heaton et al., 2019; Jiao et al., 2016). This has explained the emergence of different research lines related to technology transfer (Bercovitz & Feldman, 2006; D'Este & Perkmann, 2011), industry-university collaboration (Perkmann et al., 2013; Youtie & Shapira, 2008), academic entrepreneurship (Siegel & Wright, 2015), graduate entrepreneurship (Guerrero & Urbano, 2019), and eco-systems of innovation and entrepreneurship (Autio et al., 2014). The phenomenon of entrepreneurial universities is embedded in dynamics that highlight the prominent role academic organizations play in shaping aggregate capabilities within eco-systems (Audretsch et al., 2019; Autio et al., 2014; Chen & Kenney, 2007; Guerrero et al., 2016, 2020). Entrepreneurial universities have been considered the key agents that generate a bridge between innovation and entrepreneurship eco-systems (Autio et al., 2014).

However, the accumulation of knowledge that explains universities' contributions to regional eco-systems and development has mainly adopted a perspective based on unidirectional flows from academia to markets (Guerrero et al., 2015; Guerrero & Urbano, 2019). This perspective fails to address the notion of mutualism, a pivotal element of the biomimetic rationale of innovation and entrepreneurship eco-system studies (Ding et al., 2019). Mutualistic relationships involve bidirectional flows of resources and capabilities to generate interactions and value co-creation among eco-system agents (Chertow, 2000; Moore, 1996; Shaw & Allen, 2018). The adoption of a mutualistic perspective adds complexity to the role played by universities not only as providers of human capital and knowledge, but also as beneficiaries of resources and capabilities flowing from eco-systems to universities (Fischer et

al., 2018b; Guerrero & Urbano, 2019; Meng et al., 2019). So far, little is known about the content, dynamics, and effects of mutualistic interactions between universities and eco-system actors in developing economies. It is a critical element in contexts characterized by a mismatch between supply and demand for scientific and technological knowledge and a weak generation of innovations (Guimón & Paunov, 2019; Pinho & Fernandes, 2015; Wit-de Vries et al., 2019). Inspired by these research gaps, this study aims to advance the bidirectional notion of university-industry collaboration by exploring the complexity of mutualistic relationships among the actors embedded in innovation and entrepreneurship eco-systems in peripheral regions.

Drawing on the extant literature in the entrepreneurial universities' field – and their respective roles within eco-systems of innovation and entrepreneurship – this study applies a qualitative methodological design to inform eco-system theory. The research setting to analyze the bidirectional relationships between universities and actors is based on five eco-systems in the state of São Paulo that compose the main technological corridor in Brazil (the cities of São Paulo, Campinas, São Carlos, São José dos Campos, and Ribeirão Preto). Our research settings provide relevant insights into outward flows from universities to eco-system agents (Fischer et al., 2019; Schaeffer et al., 2018) and inward flows from eco-system agents to universities (Garcia et al., 2020). Concretely, our results underscore the existence of mutualism in the relationships established between universities and eco-system agents. Indeed, we identified several drivers/barriers in the bidirectional flows related to multi-scalar dimensions. Accordingly, despite being a local/regional phenomenon, eco-systems of innovation and entrepreneurship require coordinating policies and strategies across broader geographical levels. This study extends the knowledge about the role of the university in the configuration of regional capabilities associated with innovation and entrepreneurship eco-system actors (Guerrero & Urbano, 2019; Romero et al., 2020), as well as the contribution of eco-system

actors in addressing educational, economic, social and technological challenges (Audretsch et al., 2019; Guerrero et al., 2020).

After this introduction, the paper is structured as follows: Section 2 features elements from the literature that help understand the latent bidirectionality in relationships between universities and eco-system actors. Section 3 proposes the methodological design. Section 4 presents empirical results on the directional contributions between universities and eco-system actors in the five analyzed eco-systems. Section 5 discusses the findings and proposes implications for academics, policymakers, eco-system actors, university managers, and other stakeholders. Section 6 concludes with final remarks, limitations, and future research avenues.

2 LITERATURE REVIEW

The concept of Eco-systems of Innovation and Entrepreneurship (EIE) has gained traction as an analytical approach that comprehends the complexity of interactions driving competitive capabilities in regions (Alvedalen & Boschma, 2017). Conceptually, they represent a *'set of interconnected entrepreneurial actors, entrepreneurial organizations, institutions and entrepreneurial processes which formally and informally coalesce to connect, mediate and govern the performance within the local entrepreneurial environment'* (Mason & Brown, 2014:5). Drawing on biomimetic analogies, this framework focuses on the mechanisms through which socio-economic environments organize to introduce new knowledge and innovations in markets (Oh et al., 2016). Elements associated with interactions, connections, and knowledge flows lie at the heart of eco-systems of innovation and entrepreneurship (Malecki, 2018). In a recent study, Kuckertz (2019) calls for deeper interpretations of the ecosystemic metaphor to achieve a better comprehension of interactive dynamics leading to the emergence of knowledge-intensive entrepreneurship. Previous assessments have already

pointed out the pivotal role of agents' *co-evolutionary* nature when embedded in eco-systems (Carayannis & Campbell, 2009). In turn, *by adopting a systemic perspective*, entrepreneurs are affected by systemic conditions (Guerrero et al., 2020), but are also agents that modify these systemic conditions by their intervention or interactions (Autio et al., 2014). This debate has represented the foundational base of the knowledge spillover theory of entrepreneurship (Acs et al., 2009) and the consideration of entrepreneurship capital as an extension of the endogenous growth theory (Braunerhjelm et al., 2010).

Nevertheless, mutualism dynamics involving universities' connections with other agents of the eco-system remain largely uncharted. The focus has been given to academia as 'knowledge factories' where capabilities and technological assets flow to their counterparts. On the other hand, the mutualistic assessment of universities' embeddedness in eco-systems adds complexity to this debate by placing academia not only as a supplier of knowledge but also as a beneficiary of resources and capabilities flowing from eco-systems to the campus (e.g., Fischer et al., 2018b; Meng et al., 2019). In this section, we develop a bidirectional framework between universities and eco-system actors. Specifically, we analyze the interrelation of universities and eco-system actors (government, industry, research centers, investors) that can be observed at least in two directions: (a) universities fostering and improving eco-systems through their core activities and (b) eco-system actors providing conditions for innovation and entrepreneurship surroundings. From this perspective, our assessment takes the university as the focal analytical element within eco-systems dynamics.

2.1 The contribution of universities' activities to eco-systems

An extensive literature has examined universities' contribution by the spillover effects of teaching and research activities (Audretsch & Lehmann 2005). *Through teaching activities*,

universities are the key source of well-educated human capital incorporated in students and graduates (Audretsch & Lehmann 2005; Urbano & Guerrero, 2013). Given these teaching outputs, universities have been skilled labor providers, job-creators, intrapreneurs, and scientists (Guerrero et al., 2015). This human capital has been a vehicle for promoting high-growth, innovative and entrepreneurial behaviors through the higher education sector (Guerrero & Urbano, 2019; Romero et al., 2020). *Through research activities*, universities are the main source of knowledge creation via academic publications, research projects, and consultancy services (Bercovitz & Feldman, 2006; D'Este & Perkmann, 2011; Guerrero et al., 2014). Given these research outputs, universities have been perceived as key agents in the dynamics of innovation and entrepreneurship eco-systems (Asheim et al., 2011; Autio, 1998; Cooke et al., 1997; Diez, 2000; Mazzoleni & Nelson, 2007).

Another strand of the literature has examined the contribution of universities' 'third mission' (Siegel & Wright, 2015). *Through commercialization activities*, universities are a major source of knowledge transfer and commercialization via licenses, patents, intellectual property rights, and spin-offs (Bercovitz & Feldman, 2006; D'Este & Perkmann, 2011; Guerrero et al., 2015). Based on these outputs, universities are perceived as anchors of innovation and entrepreneurship eco-systems (Bercovitz & Feldman, 2006; Clarysse et al., 2014; Galan-Muros & Davey, 2019; Guerrero et al., 2016). Within this context, the phenomenon of academic entrepreneurship has emerged within universities and demanded favorable environmental conditions for accessing the resources, capabilities, and infrastructure required by researchers, academics, scientists, and doctoral students (Guerrero & Urbano, 2019; Hayter et al., 2018).

University efforts to promote entrepreneurship and generate knowledge spillovers have been important catalysts to spur eco-systems and economic growth over the last decades (Lehmann et al., 2020). Therefore, innovation and entrepreneurship eco-systems have emerged

after multiple interactions and negotiations with myriad actors looking to establish the bases of regulations (e.g., Bayh-Dole Act, higher education legislations), funding conditions (incentives, subsidies, contracts), infrastructure (hybrid organizations), and the social legitimization of academic entrepreneurs (Guerrero et al., 2020). This explains why different eco-system actors increasingly recognize the importance of scientific knowledge creation and seek alliances with universities to enhance their knowledge base and gain a competitive advantage (Tseng et al., 2020).

One of the main interactions emerging in this context is university-industry collaborations (Mao et al., 2020). This relationship has overcome academic entrepreneurship barriers and transformed value chains (Cheng et al., 2020). In this particular case, Alexander et al. (2020) explain the relevance of strategic management between academics and industry to facilitate the alignment of priorities and the flow of resources/capabilities across knowledge transfer processes. Intuitively, the university shares specialized training, technological capabilities, and infrastructure that can be transferred to or shared with companies interested in acquiring the most up-to-date knowledge for developing innovations or entrepreneurial initiatives (Perkmann et al., 2013). These spillover effects make it possible to connect actors and establish different knowledge transfer channels (Brown, 2016) for developing or co-creating innovations derived from the interactions between universities and eco-system actors (Autio et al., 2014). Such channels involve different complexity levels, comprehending activities such as routine analytical services, consultancy, joint R&D projects, intellectual property licensing, spin-offs, and qualified labor. According to Arza (2010), simpler forms of knowledge transfer can be more closely associated with unidirectional flows, where firms can benefit from efficiency gains in their operations and universities receive monetary compensations (Arza, 2010). In turn, more complex forms of collaboration lead to increased

integration between academic and firm-level activities, generating opportunities for long-term interactions and effective co-creation of innovation capabilities.

Universities' role is even more relevant in an emerging country like Brazil, in which firms have limitations in terms of innovation capabilities. Universities stand out in catching-up processes precisely because they hold the largest contingent of researchers, being responsible not only for training and research but also for their impacts on the generation of knowledge-intensive entrepreneurship (Fischer et al., 2018b; Mazzoleni & Nelson, 2007; Ryan, 2010). Hence, universities play a well-established role as key agents in configuring eco-systems of innovation and entrepreneurship (Audretsch et al., 2019), promoting regional economic growth and competitiveness (Lehmann et al., 2020) as well as fostering the entrepreneurial culture, spirit, and attitudes in society at large (Guerrero & Urbano, 2019).

2.2 The contribution of eco-system actors to universities' activities

Prior literature has examined the influence of business density proximity in transferring resources and capabilities to universities (Hewitt-Dundas, 2013). By reviewing the literature on social capital and technology transfer, we identify that building strong networks requires interaction with specialized and complementary actors (Schaeffer et al., 2020) in order to access resources, capabilities, and legitimacy as a player within innovation and entrepreneurship eco-systems (Villani & Lechner, 2020). As a result, universities in emerging countries face multiple challenges that make it difficult for them to fulfill their role as truly entrepreneurial agents.

The first flow of resources provided by eco-system actors is related to grants, incentives, funding, or R&D contracts. Financial support from governments, industries, and other agents is necessary to allocate university resources to innovation activities and facilitate the

achievement of university-industry collaboration goals (Tseng et al., 2020). For instance, in emerging economies, informal collaborative and funding platforms promoted by entrepreneurs are an excellent alternative to access funding sources and reduce the effects of institutional voids associated with R&D (Guerrero et al., 2020).

The second flow of resources from eco-system actors to academia is related to physical and hybrid infrastructures. The dynamic development of universities' core activities requires financial resources and physical infrastructures or equipment (Guerrero & Urbano, 2019). In this sense, the interaction between universities and eco-system agents makes it possible to access specific resources to create hybrid or intermediary organizations that facilitate knowledge generation, knowledge commercialization, and, ultimately, academic entrepreneurship. Typical examples of these hybrid infrastructures are technology transfer offices, business incubators, business accelerators, and science parks (Siegel & Wright, 2015). Directly or indirectly, these physical resources configure a good environment for university commercialization activities and academic entrepreneurship (Hayter et al., 2018).

Third, there are *flows of capabilities* related to the legitimacy of the third mission of universities (François & Philippart, 2019). Particularly in emerging economies, legitimacy has been the key requirement for support by eco-system actors (Schaeffer et al., 2018). Sometimes legitimacy comes from government intervention through higher education regulations or informal channels established between eco-system actors and society. Consequently, legitimacy reinforces the development of innovation initiatives within universities, generating a favorable effect on developing academic/graduate entrepreneurs and universities' innovative business models (Guerrero et al., 2020).

Under these assumptions, strong networks with eco-system actors enable strategic access to resources, capabilities, and legitimacy for universities embedded in innovation and entrepreneurship eco-systems (Schaeffer et al., 2020; Villani & Lechner, 2020).

2.3 Proposed conceptual framework

Figure 1 depicts the rationale of the bidirectional relationship between universities and different agents of eco-systems of innovation and entrepreneurship. In this framework, universities support the configuration of innovation/entrepreneurship eco-systems by developing training, research, and commercialization activities (Guerrero et al., 2015). In turn, the eco-system supports the development of universities' core activities (Guerrero & Urbano, 2019). Given the complexity involved in assessing all possible relationships among eco-system actors, this study paid special attention to the bidirectional relationship between university actors involved in core activities (i.e., teaching, research, and commercialization) and eco-system actors involved in innovation and entrepreneurship activities (i.e., research funding agencies, industry, academic spin-offs, among others).

---- Insert Figure 1 here ---

3 METHOD

3.1 Research settings

In order to analyze the role of universities in the structural dynamics of innovation and entrepreneurship eco-systems, exploratory research based on multiple cases was carried out. Our research setting is based on selecting five cities composing a thriving corridor of technological activity and generation of knowledge-intensive entrepreneurship in the state of São Paulo, Brazil (Alves et al., 2019; Fischer et al., 2018a). The selection criteria were applied

as follows. First, this sample illustrates the eco-system phenomenon from the perspective of a developing country, thus adding novel insights on the local-level dynamics of innovation within the reality of a peripheral economy. Second, it comprises the central area of economic activity in Brazil, accounting for nearly a third of its GDP – even though it lags behind developed economies in terms of technological competitiveness (Fischer et al., 2018a). Also, the state of São Paulo concentrates approximately 30% of innovative companies in the country (IBGE, 2016) and accounts for 33.4% of patent applications filed with the National Institute of Intellectual Property (INPI, 2017). Third, universities located in the state of São Paulo concentrate roughly 20% of research groups collaborating with industry in Brazil (CNPq, 2018). Lastly, this region comprises universities with intense patenting activity (Fischer et al., 2019).

These five specific locations (the cities of São Paulo, Campinas, São Carlos, São José dos Campos, and Ribeirão Preto) allowed us to examine heterogeneous profiles of innovation and entrepreneurship eco-systems that thrive on distinct configurations of elements (Alves et al., 2019) and universities' role in different stages of eco-system development (Heaton et al., 2019). This strategic design provided us with variety in the sample, a desirable feature to observe specific behaviors concerning our empirical exercise scope.

Three cities are embedded in a context that we can define as core eco-systems (Alves et al., 2019). São Paulo, Campinas, and São José dos Campos are located geographically close to each other and form a geographic triangle in which commuting between them takes about 90 minutes by car (100 miles). Indeed, these cities share strong similarities in their respective eco-system characteristics, like the concentration of incumbent firms, including multinational corporations, accumulation of knowledge-intensive jobs, and high urbanization rates. In the case of *the city of São Paulo*, the state's capital and central economic hub, we have the backbone of a world-level metropolitan area with over twelve million inhabitants. Several of

the best universities and research organizations in the country are based in São Paulo, including campuses of the University of São Paulo (USP), the Federal University of São Paulo (UNIFESP), and the State University of São Paulo (UNESP), three of the leading higher education organizations in Brazil. The Federal University of ABC (UFABC) is situated in an adjacent location within the same metropolitan area. Other relevant organizations include the Institute of Technological Research (IPT) and the Butantan Institute, a research institute for vaccine research. In the case of *the city of Campinas*, it is a medium-sized city with just over one million inhabitants.

Located in a secondary metropolitan area, Campinas is one of the leading technology hubs in Latin America, concentrating on R&D centers of private companies and public research organizations. In historical terms, Campinas was the first location in Brazil outside Rio de Janeiro to receive a research institute: the Agronomical Institute in 1887. Over the years, its trajectory brought together research facilities in information technology funded by the federal government. The city also houses the largest particle accelerator in the Southern hemisphere, located inside a research park dedicated to energy and materials. In the 1950s, the University of Campinas (UNICAMP) was founded. This higher education institution was created to establish ties with industry, thus leveraging competitiveness in the region. This city also has three operational Science Parks attached to public and private organizations. Unlike the significantly diversified economic context of the capital, São Paulo, Campinas is more strongly directed towards ICT sectors. In the case of the city of *São José dos Campos*, it is known worldwide for housing the headquarters of the Brazilian aircraft manufacturer, Embraer. A series of public policies have engineered this city to be a leading hub in distinct areas associated with aerospace science and related industries. With 700 thousand inhabitants, São José dos Campos concentrates on the National Institute for Space Research (INPE), the Department of Aerospace Science and Technology, and the Aeronautics Institute of Technology (ITA). The

city also has two Science Parks in operation. Another relevant feature of this eco-system concerns that São José dos Campos is situated in a strategic geographical location, along the massive conurbation that connects São Paulo to Rio de Janeiro, which comprehends over forty million people and responds for over a third of the Brazilian GDP.

The two other cities (*São Carlos and Ribeirão Preto*) included in our analysis represent somewhat distinct trajectories in terms of eco-system configurations compared to the locations described above. While they also rely on competitive research universities and the availability of skilled labor, the cities of São Carlos and Ribeirão Preto have lower levels of business concentration and lack a solid base of multinational corporations (Alves et al., 2019). They are also located outside the direct reach of the central economic hub, São Paulo, which characterizes these cities as relatively peripheral eco-systems. In the case of the city of *São Carlos*, it is the smallest municipality in our sample. With a population of 240 thousand inhabitants, the city has long been acknowledged as an important technological hub in Brazil. It has two campuses of the University of São Paulo and also houses the Federal University of São Carlos (UFSCar), both top-tier universities in Brazil. The Brazilian Agricultural Research Enterprise (Embrapa), a public company dedicated to agricultural research, has two units in this city. Two functional Science Parks are also located in São Carlos, and the municipality has the highest levels of knowledge-intensive entrepreneurship in the state of São Paulo and one of the highest levels of patent deposits per capita (Fischer et al., 2018a). Lastly, *Ribeirão Preto* is an interesting case of a city with dedicated efforts to shift from an economic structure based on sugarcane agricultural activities to a knowledge-based economy. With nearly 700 thousand inhabitants, Ribeirão Preto also has a campus of the University of São Paulo. Over recent decades this city has established noticeable health sciences capabilities, promoting the upsurge of several ‘health tech’ start-ups, mainly located in or close to its Science Park.

3.2 Research Design

The research design included interviews with technology transfer offices, leaders of research groups, research centers, and knowledge-intensive companies¹. We decided to interview leaders of research groups and research centers because several technology transfer processes and linkages with the innovation eco-system are managed directly by researchers. At the same time, TTOs are mostly responsible for the management of intellectual property rights. This feature was confirmed in our empirical appraisal, especially concerning star scientists² who already have dense and consolidated networks outside academia. Also, by interviewing these researchers, it was possible to obtain a critical view of the role played by TTOs and a more precise perception of the dynamics of interaction between research, teaching, and entrepreneurship activities of researchers. Adopting the multiple case approach afforded a more robust and testable perspective of the phenomenon under study (Eisenhardt & Graebner, 2007). This methodological choice also aimed at reducing interview bias.

We used research protocols covering seven dimensions of analysis: structure and resources, technology transfer, generation of spin-offs, generation of results/impacts in general, internal barriers, the geographical dimension of eco-systems, and context (see Appendix A). Based on a literature review, our protocols were structured for each type of actor interviewed. Although some questions were marginally adapted to address each group of subjects' particularities, all scripts covered the seven dimensions of analysis cited above. The final versions of protocols were iterated and validated by two external auditors with extensive

¹ In order to identify knowledge-intensive companies we used data from companies participating in the Innovative Research in Small Enterprises Programme (PIPE). Created in 1997 by the São Paulo Research Foundation (Fapesp) and inspired by the US Small Business Innovation Research (SBIR), the programme supports entrepreneurial projects with a high level of knowledge intensity and innovative potential (Salles-Filho et al., 2011).

² According to Crescenzi et al. (2017), star scientists are academics familiar with innovation and entrepreneurship activities, being responsible for the success of new businesses generation and for bringing universities closer to the productive sector.

academic and practical expertise in the field. The research design stage – involving sample definition and elaboration of protocols – was conducted in 2017/2018.

3.3 Data Collection

Qualitative data collection was organized in the first semester of 2018, considering the identification of potential interviewees from secondary sources. Also, initial contacts and logistic arrangements were organized before the interviews, which were conducted over the second semester of 2018. At the university level, the interviews included technology transfer offices, leaders of research groups, and research centers. The universities included in the study are: University of São Paulo (USP - São Paulo and Ribeirão Preto), University of Campinas (UNICAMP - Campinas), Federal University of São Carlos (UFSCar - São Carlos) and Aeronautics Institute of Technology (ITA - São José dos Campos). Additionally, the TTO of the National Institute for Space Research (INPE - São José dos Campos) was interviewed, as was the TTO of the Federal University of ABC (UFABC - Santo André), which belongs to the São Paulo innovation eco-system, as this is a young university that was established to connect and support its innovation and entrepreneurship eco-system. These universities are all research-intensive and are among the top universities in Latin America according to the Scimago ranking. Besides, USP is one of the oldest universities in the country that explains its deep embeddedness in the eco-systems it belongs to. These aspects signal the relevance of the cases under analysis. A thorough overview of these organizations is provided in Table 1.

---- Insert Table 1 here ---

The choice of research group leaders was based on the CNPq Research Group Directory Census³ of 2016, and the most interactive research groups in each university were identified based on collaborations with industrial partners. The content of interactions was also analyzed to target groups establishing R&D-oriented ties. Research centers were mapped according to the information available on the vice provost office website for the research of each university. We selected research centers that had interactions with the productive sector, most of which are part of the Research, Innovation, and Dissemination Centres Programme (RIDCs) of the São Paulo Research Foundation (Fapesp)⁴, signaling the excellence of the selected centers.

Within the entrepreneurship eco-system, companies of the PIPE/FAPESP Programme were interviewed. Most of these companies had a history of relationships with the universities participating in the research. They provided the study with an external view of the university's role and the bidirectional flows of knowledge and information, which had already been detailed by research group leaders and research center coordinators. Importantly, these companies are essentially knowledge-intensive, which qualifies their participation in the research and allows the authors to gain insights into the entrepreneurial dimension of the innovation eco-system.

In total, 25 interviews were undertaken with 21 different actors: five TTOs, five research groups, six research centers, and five PIPE companies⁵. All respondents were initially contacted by telephone and then received an email containing all the interview details to be

³ The CNPq Research Groups Directory Census is a database of scientific and technological activities in Brazil. Information about research groups includes data on human resources (researchers, students and technicians), lines of research, sectors of application involved, scientific, technological and artistic production, and collaborations established by formal research groups.

⁴ The RIDCs Programme was launched in 2000 by Fapesp as an initiative to develop fundamental or applied research, focused on specific themes that actively contribute to scientific advances, knowledge diffusion and innovation. In total, 17 centers in the State of São Paulo are supported by the Programme.

⁵ Additional interviews were undertaken with one TTO, one research group, one research center, and one PIPE company. The objective of these additional interviews was to have access to information that was not known by the original interviewees. First, the additional interview with one TTO was conducted with its former director, as the current director had taken over recently. The additional interview with the research group was carried out because the group had more than one line of research, with different coordinating professors. In the case of the research center, the interview was with the former director, responsible for founding and coordinating the institution for over 20 years. In the case of PIPE, in addition to the founder, the current CEO (the surrogate entrepreneur) of one company was interviewed.

held. The interviews were face-to-face, recorded, and later transcribed for analytical purposes⁶. The interviews lasted an average of 64 minutes (Table 2).

---- Insert Table 2 here ---

Following Yin's (2002) triangulation approach, we used complementary sources of information collected throughout the empirical exercise (2017-2019). These sources are described below:

- i. *TTO annual reports of USP, UNICAMP, UFSCar, ITA, INPE, and UFABC*: patents, licenses, revenues, collaboration agreements;
- ii. *Research Group Directory Census from the Brazilian Research Council (DGP/CNPq)*: data of collaborations established by formal research groups. It includes information related to location and sector of the firms and the type of collaboration established;
- iii. *University websites of USP, UNICAMP, UFSCar, ITA, INPE, and UFABC*: information regarding the university's mission, organization, and institutional structure, and main research centers;
- iv. *São Paulo Research Foundation (Fapesp) website*: data of research grants and projects, research centers and knowledge-intensive entrepreneurship (PIPE companies), and other indicators related to universities;
- v. *Websites of knowledge-intensive entrepreneurial companies (five PIPE companies interviewed)*: characterization of companies in terms of sector, number of employees, location, history, main activities.

⁶ This procedure follows recommendations of the Research Ethics Committee of the University of Campinas. The interviews were approved under protocol #89010418.2.0000.8142/Project 'Universities as Pivotal Agents in Innovation Ecosystems'.

These multiple sources made it possible to triangulate the information collected.

3.4 Data Analysis

Qualitative data analysis followed the content analysis method (see Figure 3 for an overview). Coding and identification techniques of the major categories were used (Strauss, 2003), and entries were categorized according to each actor interviewed. In the categorization, we sought to identify relationship patterns between the constructs proposed in the theoretical model and the data collected in case studies (Eisenhardt & Graebner, 2007). One of the authors initially proposed data categorization based on the transcripts and subsequently revised and discussed by the other authors. Analytical categories followed the dimensions proposed in the research protocols. First, results regarding the role of universities in innovation and entrepreneurship eco-systems are described and analysed. Second, we discuss how the eco-system actors support the role played by universities, i.e., how flows of knowledge and information assume bidirectional, mutualistic features.

4 RESULTS

The findings suggest that universities play a pivotal role in the analyzed eco-systems. This insight goes beyond formal relations to also include informal relations with firms and students with entrepreneurial intentions. Moreover, it was possible to identify that universities also depend on the firms' support with which they interact. In this sense, industry plays an important role in bringing academia closer to market practices and other commercial partners, characterizing typical mutualism in the established bidirectional relationships. This notion goes beyond the perception of the university as solely the origin of technological capabilities

(Bercovitz & Feldman, 2006; Chen & Kenney, 2007; Mazzoleni & Nelson, 2007; Youtie & Shapira, 2008), viewing instead as an element that co-exists in positive symbiosis with other elements of the eco-systems. A broad context of the collected information is drawn in Figure 2.

---- Insert Figure 2 here ---

4.1 The role of universities in innovation and entrepreneurship eco-systems

In this stage, we tried to identify the university's mission from the perspective of the interviewees. Collaborations with external actors, while being of a global nature in most cases, as mentioned by research center coordinators and research group leaders, are also locally embedded. This is even more relevant in the case of INPE, as the aerospace industry is geographically concentrated in the same location as the research institute. Other researchers also noted the importance of face-to-face interactions in sharing tacit knowledge. Thus, the geographical concentration of collaborations relates more to an overlap between regional productive specialization and university activity than a local interest of researchers. The second observation is that not all interactions are formal, especially considering research groups. Since many researchers already have personal contacts with actors in the productive sector, knowledge and information flows are not restricted to the formal mechanisms of collaboration.

The supply of qualified human resources is highlighted as one of the most significant contributions of academia to eco-systems, but the relevance of research and innovation activities has also been underscored. The interviewees mentioned the connections with the eco-system, emphasizing the generation of technological, scientific, and social development in their regions. According to the director of one TTO, industrial development is based on academic

research. Thus, although teaching activities are still perceived as the most relevant, it is observed that other elements that compose the third mission of universities were also mentioned. In this regard, the interviewees emphasized the view of economic and social development:

'We hope the knowledge developed within the university will reach society. That is, that the knowledge is turned into economic wealth. That the knowledge of the university becomes innovation that will be used, that can be absorbed by the company, which then generates revenues because it is commercializing the product on the market, generating jobs, generating taxes. The TTO generates wealth and economic development through knowledge transfer' (Head of TTO).

4.1.1 Collaboration dynamics

These collaborations with the productive sector are usually initiated through the personal contacts of the researchers. Only recently have TTOs taken a more proactive attitude. Participation in business events, the search for contacts in companies that invest in R&D, and the creation of industrial graduate programs are still incipient and poorly structured. In this sense, one respondent noted the need for a more automatic process to connect local demands with academic expertise. It could result in alignment between the university's scientific and technological knowledge and the productive specialization of each region.

Regarding TTOs specifically, the regulatory framework that instated these structures in public universities was established in 2004 by the Brazilian Innovation Act (Law 10,937). USP, UNICAMP, and UFSCar are exceptions as they established their respective TTOs before the law was enacted - although with names or structures different from current configurations. Thus, the TTOs included in our interviews were, for the most part, relatively young, with little over a decade of existence. As defined by law, these TTOs have four guiding duties: (1) to

support intellectual property activities; (2) to promote technology transfer; (3) to promote collaborative projects between universities and the productive sector; and (4) to foster academic entrepreneurship. Except for the offices of USP and UNICAMP, it is noted that the other TTOs have a lean structure and constant budget constraints, which makes it impossible for them to hire specialists on the subject and, especially, to achieve their different objectives. Among the activities performed by TTOs, intellectual property support is the most important. This is confirmed by patent data, given that USP and UNICAMP are listed among the top 10 patent applicants with the national patent office among all organizations (INPI, 2017).

Universities are also seeking to play a more active role in IP portfolio management. In addition to maintaining online repositories of patented technologies, they organize events with the productive sector to disclose their patents. Another strategy to bring universities closer to their eco-systems is the development of co-patents. According to Orbis Intelligence database, on average, 30% of patents filed by USP, UNICAMP, and UNESP had other organizations as co-assignees⁷. This percentage is even higher in the specific case of UFSCar, which has a 50% co-patent rate. Several examples of this practice were observed in the collaborations established by research centers, especially in the case of the UFSCar research center and two UNICAMP research centers. In this context, as pointed out by two interviewees, the researcher has a more active role in technological forecasting that involves development processes. Such an approach also avoids excessive patent applications by university researchers who focus on this activity solely to improve their performance indicators.

Additionally, co-publications with industrial researchers are also common, especially in the case of research groups. These joint publications are valued not only by academic researchers but also by companies that highlight this as a credibility certificate of industrial

⁷ Co-assignees are other organizations (universities, research organizations, public organizations, firms, etc), located or not in the same ecosystem, that share with the universities the intellectual property rights of inventions.

research and a diffusion mechanism for developed technologies. In the state of São Paulo, 2.5% of articles published by universities from 2015 through 2017 have co-authors in the business sector. This percentage ranges from 1.7% in the case of UNESP to 4.4% for papers published by ITA, which has the highest rate.

The research centers are examples of academic initiatives geared towards connecting the university to innovation and entrepreneurship eco-systems. Focused on teaching and research activities, the centers also play an essential role in innovation diffusion. Among the centers interviewed, some had connections with the productive sector from their inception, while others started to collaborate with companies due to the need to transfer the developed technologies. Collaborations with companies, both national and multinational, are focused on joint research projects, but teaching activities focused on firms' needs, and technological services are also frequent. It is noteworthy that the research centers are partially funded by resources from the industry, which highlights the importance of these resources for maintaining grants, scholarships, equipment, inputs, and infrastructure. Research groups also use project and service resources to fund student activities and maintain research labs. One interviewee provides insight into the linkages between science and innovation:

'If you look at the participation of Brazilian science by the number of publications, you will see that Brazil has 2% of the world's scientific publications. The impact of this science is a few steps below the world average. But if you look only at plant science, you will see that 10% of all plant science produced in the world is produced in Brazil. And the impact is much greater, some steps above the world average. Perhaps the explanation is that this science has always been focused on solving real problems arising from food production, agriculture, livestock and so on' (Head of Research Centre).

These insights reflect the intense connection with the problems in this area. Thus, the discoveries made in university laboratories result from needs from the productive sector, which generate advances in science.

4.1.2 Academic entrepreneurship

The promotion of entrepreneurial activity, both internally and externally, occurs through incubators, science and technology parks, co-working spaces, and entrepreneurship courses for students, lectures, and events. Although the overall number of spin-offs⁸ from the universities analyzed is modest compared with the impacts generated by leading universities such as the Massachusetts Institute of Technology (Roberts et al., 2019), some results are noteworthy. UNICAMP, for example, has over 800 registered spin-offs, generating roughly 30,000 jobs and USD 3.5 billion in revenue annually. These companies include ventures created by alumni and current students, staff, and faculty. Nearly 65% of these companies are in the Campinas region, confirming the connection with the local entrepreneurship eco-system.

Academic spin-offs also stood out in interviews with research centers and, to a lesser extent, in interviews with research groups. Given that the interviewed centers are recognized for their excellence in research activities and connections to markets, they also generate several spin-offs that are usually located near the university. These spin-offs tend to continue to collaborate with the research centers, reinforcing the strong ties in the entrepreneurship eco-system. The star scientists who coordinate the research centers have generally been academic entrepreneurs and seek to foster this profile among researchers. In this sense, the main incentive towards entrepreneurship is related to access to diverse funding sources, as stated by one of the interviewees.

⁸ In This case, the spin-off concept encompasses any individual affiliated with the university who creates a new business, or any entrepreneur who creates a new firm to explore the intellectual properties generated at the university (Hayter et al., 2018; Urbano & Guerrero, 2013).

'The companies are coming. This is even a demand from [...] to foster business creation. The Oil Act⁹ has changed, so there is the possibility of investing in the company. So, we can use part of this money that would go to research to foster companies, start-ups, and everything. But this is still very recent, since 2015/2016. People are still trying to understand how it works' (Head of Research Centre).

ITA mentioned another initiative to foster entrepreneurship. This organization has a minor program that seeks to engage undergraduate students in projects proposed by the institute's researchers. Students who enroll in the projects take specific courses related to the research topic and deliver a prototype or a new development. This initiative aims to develop applied scientific research, integrate innovation in the curriculum and promote entrepreneurial activity.

4.1.3 Challenges and barriers

There are still several factors that limit universities from performing all functions encompassed by the third mission concept. Current legislation in Brazil imposes a series of restrictions on the performance of the entrepreneurial activity by professors and employees of public universities. For instance, there is an underlying difficulty in transferring and licensing these technologies. Among the key challenges is the regulatory framework that hinders the commercialization of IP owned by public entities in Brazil (Fischer et al., 2019). In this regard, some possibilities open up with the new regulatory framework (Law 13243/2016, also known as the New STI Legal Framework), such as licensing technologies without having to undergo public bidding. Previous bureaucratic procedures ended up alienating interested companies

⁹ According to the Oil Act (Law 12351/2010), 1% of the profit accruing from Brazilian oil fields must be invested in research in the country. Half of this percentage can be invested in firms' internal R&D activities and the other half necessarily needs to be used to finance research carried out by Brazilian universities and research institutes.

because patent confidentiality is broken, and there is the chance of a competitor ultimately obtaining the associated intellectual property rights. Organizations are still adapting to the new legislation, and while perceptions are positive regarding regulatory changes, practical impacts could not be reported by interviewees.

'In our case, generation of innovation is a broader concept than the transfer of technology. In fact, you can only generate innovation if technology transfer happens. However, the legal framework that allows you to transfer technology is being consolidated only now with the New STI Legal Framework. It is only now that you have, for example, a sufficiently detailed regulatory framework that can be applied without creating a legal problem for technological procurement' (Head of TTO).

Another barrier relates to budgetary constraints, which hampers TTOs from participating in venture capital programs to hire and retain qualified staff to perform the necessary tasks. Conflicts of interest are also an obstacle cited by TTO managers, particularly for contracts negotiated directly by researchers. From the perspective of research center coordinators, some universities provide greater support in terms of infrastructure and staff, while other centers make minimal use of university resources. Additionally, centers and groups reinforce that they only use TTOs when they need help to negotiate IP rights, as offices often pose bureaucratic hurdles, lack qualified staff, and a more proactive and prospective approach to collaborations with industrial partners.

Future challenges for universities within their innovation and entrepreneurship ecosystems include the need to raise researchers' awareness about the importance of collaborating with external actors, developing competencies concerning technological valuation, enhancing the creation of new ventures, and reviewing performance indicators to offer a more comprehensive set of incentives conducive to the notion of the entrepreneurial university. Finally, the university must legitimize its missions and its role in society. Two respondents pointed out this issue as the main challenge, especially in periods of financial constraints. It is

increasingly necessary to show society the results and impacts generated by academic activities. Initiatives need to be practical and bureaucratic, as mentioned by the research centers coordinator.

4.2 Eco-system actors supporting universities' role

The role of eco-system actors is central to the concept of the entrepreneurial university. The role of these agents goes well beyond the idea of recipients of academic knowledge. It can be observed that the companies interviewed, as well as the state funding agencies, establish close relationships characterized by an intense exchange of information and knowledge with universities. External agents not only recruit human resources and set up research projects with academia but are also responsible for: (1) funding university activities in terms of scholarships, equipment, and infrastructure; (2) exploiting intellectual property rights, generating revenue that is reinvested in research activities; (3) generating new ideas and opportunities to be explored in teaching activities; and (4) helping universities foster academic entrepreneurship, either through mentoring or financial resources to create new spin-offs.

4.2.1 Training flows

Research centers and groups highlighted the impacts of collaborations with the productive sector in teaching activities. Linkages with industry provide the generation of new scientific ideas, which can be explored in dissertations and theses. New disciplines, courses, and training for undergraduate and postgraduate students are also offered through collaboration with external actors. Also, experiences with real examples help researchers bring empirical

cases into the classroom, which often attracts students' attention and puts them in touch with research results on the frontier of knowledge.

From the industry's perspective, the owners-managers noted that some product testing is only possible with university infrastructure support. The use of equipment and laboratories available in academia is a routine practice among firms, especially young companies with no research and development facilities. Sharing of academic facilities creates daily interactions between researchers and students, allowing an easier exchange of information among people involved in these practices. Additionally, one company mentioned that its software is available free of charge to students of its *alma mater*, generating learning and feedback on technology use. When collaborating with companies that are R&D-intensive, students automatically have access to current infrastructure, equipment, and instruments, which are sometimes not available at universities.

Internship and employment opportunities are also made possible through collaborations with external partners. According to research group leaders, companies with which they collaborate formally and informally often request students to fill positions, strengthening ties between agents. The firms also mentioned that they seek to recruit people at universities and encourage their employees to pursue postgraduate programs focused on solving real problems. While recruitment relationships occur with various universities, postgraduate training activities and research projects are usually established with universities recognized for their academic excellence and research intensity. In this view, one interviewee stated:

'When you think about training, there are stark differences between research-oriented and teaching-oriented universities. A university that is not focused on research merely presents what is presented in engineering books. In a research-intensive university, in addition to having access to what is in the text and how they should learn, students end up having contact with the results of research at the frontier of knowledge' (Scientific Head of Research Centre).

In this example, most research projects take place in close collaboration with firms, bringing students closer to highly applied concepts and techniques. This dynamic interaction between academia and the productive sector allows the expansion of students' capabilities beyond in-class training.

4.2.2 Financial flows

Collaborations with the industry help fund the activities of research centers and groups. For example, in one of the analyzed cases, the purchase of prototyping equipment was only possible through interaction with a company. In turn, the research group will now make this machine available to be used by undergraduate students, generating learning opportunities.

Regarding academic entrepreneurship, it is important to highlight the role of Fapesp, the São Paulo Research Agency. Research center coordinators and research group leaders stressed the importance of the PIPE Programme as a conduit for knowledge-intensive entrepreneurship. According to interviewees, most academic spin-offs were founded with the financial support of this initiative. Because they are companies based on research activities, these projects involve a high degree of risk, reinforcing the importance of having public support and investment, considering their lack of attractiveness to private funds in the early stages of development. Researchers seek to encourage their students and peers to submit projects to this funding program. Moreover, PIPE companies mention that they became aware of it through professors and that their participation was only possible because they used the scientific knowledge and structure available at the university. Consequently, Fapesp plays a central role in helping the university fulfill its entrepreneurial mission.

'So, when I participated in PIPE projects, I always asked myself: what interests me?

Let's ask for scholarships. We are going to develop things. So, we will have part of the

projects that will be developed in the area that I know. These funded fellows will stay with me. I will help select them, and we will transform this, as far as possible, into academic research projects. [...] It is an interesting way to give something back, as it increases the possibility of financing. Or else you will ask for equipment, something will stay in the laboratory. And we are going to work and, after we finish, we are going to donate it to the university' (Leader of a Research Group).

Another finding was the importance of alumni networking. One of the academic spin-offs was only founded through investment by alumni of its researcher and founder. Thus, a technology developed at the university only hit the market thanks to the researcher's network reaching out beyond the academic environment and the interest of alumni in investing in this new venture. External actors also play an important mentoring role for academic spin-offs. The founder of one of the companies cited the entrepreneurs' belief regarding their responsibility of giving something back to the entrepreneurial eco-system. He particularly seeks to mentor companies in the incubator of his *alma mater*, fostering an academic entrepreneurship culture in the university.

4.2.3 Spin-off flows to the university

It was possible to identify that entrepreneurial firms have close relations with universities. Some of these collaborations are focused on training qualified human resources, while others are targeted at R&D projects. Collaborations with universities mark the trajectory of the companies surveyed since their foundation. Several firms participating in the research were born from ideas created within the university environment, which was highlighted as a meeting place for people, ideas, knowledge, and opportunities. Illustratively, the idea of founding one of the companies emerged when its partners took part in exchange programs during their undergraduate studies, where they came into contact with the technology and the

product that would later be improved and developed in Brazil. The company was established in the incubator of the partners' *alma mater*. Currently, the venture is located in the city's Science Park, and it still maintains intense collaborative relationships in terms of research projects and teaching activities with the university. Also, it was mentioned that the university's entrepreneurial environment was a determining factor in choosing where the company would be based.

Another case that confirms the relevance of these bidirectional flows and, more specifically, the role that external actors play in supporting the university's role can be observed in another interview. The start-up was founded based on academic discoveries in health technologies, and the firm maintains research projects with universities throughout the state of São Paulo. As noted by the company's CEO, their technology can be used as a platform for progress in science:

'We define that the purpose of the company is to challenge current medicine paradigms to create stories of health and happiness. So, to challenge medicine, we have information that no one could have, and, as a strategy, research is the cornerstone of our activities. Scientific research is our marketing. [...] There is no way to [...] move forward without scientific research' (CEO Interviewed).

4.2.4 Challenges and barriers

TTOs noted that time perceptions and priorities differ between universities and the productive sector. Abusive contracts are also a difficulty that needs to be circumvented from the perspective of TTOs. Another limitation cited by these actors is that industrial demands are still very low, especially in pharmaceutical sectors, requiring companies to propose new challenges for researchers. In this regard, one interviewee stated:

'The productive system demands little from the scientific system, and we see it clearly in the region of [...]. Production units are reproductions of the headquarters of multinational companies located in the region, and small and medium-sized companies are part of global chains whose production processes are closely linked to the demands of large companies. So, they have low levels of innovation locally' (Head of TTO).

Research center coordinators, research group leaders, and firm representatives point to potential alignment conflicts between academic and industrial objectives. Companies mention that they perceive proactive behavior by researchers despite the university bureaucracy that all respondents mentioned. Also, they cited that public universities should behave more entrepreneurially and be less averse to inflows of financial resources from private enterprises, which can be a major funding agent for academic activities in periods of budgetary constraints.

4.3 The influence of geographical location

A last empirical aspect that deserves attention concerns the heterogeneity found in mutualistic symbiosis in different eco-systems of innovation and entrepreneurship. Although the five analyzed cities are located in the same state, they present distinct socio-economic maturity levels, which appears to affect the reach of connections established by universities (local, regional, national and international) and their bidirectional nature. Universities embedded in more complex economic fabrics (the cities of São Paulo, Campinas, and São José dos Campos) seem to receive greater benefits from connections with industrial partners. Simultaneously, in relatively peripheral eco-systems (Ribeirão Preto and São Carlos), academic contributions demonstrate a prevalence of unidirectional technology transfer processes. This might be due to a stronger local nature of university-industry connections in these eco-systems, provided they have achieved higher consolidation in terms of actors and

organizations. Sectoral characteristics of industrial partners also shape the fluidity of bidirectional flows of knowledge and resources.

Another noteworthy aspect of the geographical nature of these eco-systems of innovation and entrepreneurship is related to their intrinsic interrelatedness. Since they are geographically close to each other, existing flows of people, knowledge, and resources somewhat blur their boundaries. Also, organizations like the São Paulo Research Agency (Fapesp) act as a ubiquitous element across all eco-systems under scrutiny. The same goes for federal-level agencies that foment scientific research and regulate university-industry connections to a lesser extent. Lastly, universities involved in frontier research establish intense linkages with international academic counterparts, thus functioning as boundary spanners of eco-system capabilities.

5 DISCUSSION

5.1 Academic contributions and research agenda

This study contributes to the entrepreneurship debate about the bidirectional relationship between university activities and eco-system actors. More concretely, the involvement of universities in the configuration of capabilities associated with innovation and entrepreneurship eco-system actors (Guerrero & Urbano, 2019; Romero et al., 2020), as well as the contribution of eco-system actors to university activities and challenges (Audretsch et al., 2019; Guerrero et al., 2020). Paying attention to the dynamics of university-industry collaborations, Figure 3 proposes a revised conceptual framework for exploring the bidirectional relationship between university activities and eco-system actors across economies.

---- Insert Figure 3 here ---

A set of propositions have emerged from this study to guide the agenda of this new research line.

First, universities play a pivotal role in developing innovation eco-systems by fostering entrepreneurial innovations based on knowledge transfer and linkages with local firms (Heaton et al., 2019). Directly or indirectly, universities help eco-system actors by creating dynamic capabilities (i.e., innovative and entrepreneurial). Therefore, when bidirectional flows occur, the university's role is legitimated and strengthened (François & Philippart, 2019), allowing it to evolve into a pivotal element of interactions based on technological development and diffusion (Schaeffer et al., 2018). However, little is known about the bidirectional relationships and the generation of dynamic capabilities evolving from these linkages. Based on these assumptions, we suggest adopting the knowledge spillover theory of entrepreneurship and dynamic capabilities to explore the following proposition.

***Proposition 1.** The contributions of universities to innovation and entrepreneurship eco-systems are enhanced when university connections with surrounding contexts rely on mutualism. An example of mutualism in university-industry collaborations involves not only unidirectional flows of resources from academia to markets. Rather, it conveys the notion of bidirectional flows of multiple resources and capabilities.*

Second, bureaucratic issues and misalignment have been addressed in prior studies to facilitate technology transfer from universities to markets (Alexander et al., 2020). However, little is known about the challenges of the closer interaction between business density and university campuses (i.e., what type of facilities are shared among them or what type of strategies should be implemented to manage the flow of resources, capabilities, and knowledge

transfer). As it turns out, these issues are interrelated, and they hamper the acquisition of legitimacy by universities *vis-à-vis* industrial agents (Villani & Lechner, 2020). This could explain the difference in terms of demands of firms to universities in emerging economies to those taking place in developed countries (Fischer et al., 2019; Pinho & Fernandes, 2015). Therefore, to enhance aggregate levels of competitiveness, eco-system actors need to achieve a mutualistic symbiosis between universities and the broader eco-system. Nonetheless, we still lack knowledge on the management side of bidirectional relationships between universities and industry. Based on these assumptions, we suggest the strategic management approach to explore the following proposition.

***Proposition 2.** The lack of proper managerial structures to tackle barriers to technology exchange between universities and industry reduces perceived mutualism levels in the eco-system. This situation hinders the creation of synergies, thus negatively affecting co-evolutionary processes of eco-system components.*

Third, academic entrepreneurs are key enablers of universities' connections with the eco-system by strengthening knowledge transfer and establishing ties with incumbents (Fuster et al., 2019). More concretely, academic entrepreneurs maintain their relationships with universities via training, mentoring, or funding (Guerrero & Urbano, 2019). As a return, academic entrepreneurs bring back to universities a set of dynamic capabilities that are not available in these organizations, such as entrepreneurial culture, attitudes, and role models. As a result, new entrepreneurial dynamics emerge within academic contexts through new generations of graduates and academics. Subsequent ties continue to be reinforced between different generations of entrepreneurs and their universities (Civera et al., 2019). However, the dynamic and bidirectional relationships among multiple generations of entrepreneurs and their

incumbent universities remain scarcely addressed by the literature. Future research should consider an evolutionary approach to explore Proposition 3.

Proposition 3. *Academic entrepreneurs' participation in the dynamics of eco-systems goes beyond the practice of technology transfer from universities to markets. Academic entrepreneurs also reinforce the formation of an entrepreneurial culture within academic contexts by maintaining strong ties with their universities.*

Fourth, although we look into innovation and entrepreneurship eco-systems with a local emphasis, the analysis highlights the critical role of multi-scalar contexts into bidirectional flows. Bidirectional relationships can be triggered or hampered by regulations, international practices, and cultural behaviors that go beyond a local geographical scope (Guimón & Paunov, 2019). The third mission of universities needs to gain legitimacy from local/international eco-system agents because entrepreneurial and innovation initiatives coming from universities raises doubts about economic feasibility (François & Philippart, 2019). Nonetheless, there is a lack of agreement on the effectiveness of regulations that promote partnerships between universities and industry (Cunningham et al., 2019) and their influence on bidirectional flows within these partnerships based on different contexts (Guerrero & Urbano, 2019). Future research should consider a geographical approach and an institutional economic approach to explore the next proposition based on these assumptions.

Proposition 4. *Challenges to mutualism for universities embedded in eco-systems of innovation and entrepreneurship are multi-layered. Any collaboration involves barriers at the level of universities, firms, support agencies, and among other actors (local, regional, national, and even international scale). The challenges of bidirectional flows could differ in peripheral regions (highest intensity) and central (lowest intensity) regions.*

5.2 Implications for university managers

The study provides insights into the relevant bidirectional contribution of universities within eco-systems of innovation and entrepreneurship. Therefore, university managers should disseminate their contributions to legitimize and position their universities as pivotal agents for promoting technological activity, innovation, and knowledge-intensive entrepreneurship. Second, our findings highlight the need for university managers to implement strategic actions and mechanisms to manage the flow of resources and capabilities that their universities share with eco-system actors. While important complementarities exist amongst these actors, challenges and barriers to closer integration still exist. This calls for the creation of hybrid sub-organizations within universities that can facilitate research commercialization.

5.3 Implications for policymakers

The study shows the need for coordination of regulations at different scales. National laws should regulate technology transfer and scientific infrastructures, while programs should be implemented at the state level to support university collaborations with eco-system agents. This situation underscores the fact that although eco-systems are locally embedded, their institutional environment is influenced by broader environments. Second, policymakers in emerging economies could design incentives to support bidirectional flows within university-industry relationships. Third, governments could create an inventory or statistics about the capabilities created by universities and industries per region, thus facilitating the governance of eco-systems of innovation and entrepreneurship. Fourth, because of the nature of scientific research, universities that engage in frontier research are likely to become connected to

competitive international networks. In turn, they might act as eco-system boundary spanners in terms of advanced knowledge. From this situation, initiatives that foster high-quality science and academic internationalization can have pervasive effects on eco-system capabilities over the long term.

5.4 Implications for industrial stakeholders

For local companies, mainly for knowledge-intensive entrepreneurial ventures, the study shows the bidirectional benefits of university and industry collaborations. Closer interaction between entrepreneurs and academic organizations can leverage the competitive capabilities of the former while feeding back the system with the generation of a stronger entrepreneurial culture in students and academic staff. Second, for large indigenous firms and multinational companies that enter developing countries, the study shows the challenges to designing R&D strategy without developing ties with the university and eco-system agents. In this regard, the university can become a connecting node in the eco-system that can leverage competitiveness levels in a diversity of players, thus positively impacting incumbents' forward and backward linkages.

6 CONCLUSIONS

This study proposed a theoretical framework for eco-system mutualism involving universities and agents embedded in innovation and entrepreneurship eco-systems. We derived a set of four guiding propositions based on a qualitative analysis of five eco-systems in the state of São Paulo (the cities of São Paulo, Campinas, São Carlos, São José dos Campos, and Ribeirão Preto). From the perspective of mutualistic symbiosis, our main conclusion is that

universities' role within innovation and entrepreneurship eco-systems goes well beyond that of 'knowledge factory'. Rather, academia should be perceived as an element that connects to other 'species' in the eco-system to provide *and receive* strategic inputs. These bidirectional flows of information and knowledge nourish local innovation and entrepreneurial capabilities, especially in an emerging country context in which the productive sector still has low levels of innovation capabilities.

This study has some limitations. First, dynamic bidirectional relationships require time to achieve a maturity stage. Therefore, the analysis of dynamic bidirectional relationships requires longitudinal datasets that make it possible to understand the lifecycle of these relationships. A natural extension of this study should be the development of longitudinal case studies. Longitudinal studies will also analyze the different missions of universities in the initial development and renewal stages of innovation and entrepreneurship eco-systems as suggested by Heaton et al. (2019). Second, dynamic bidirectional relationships require a geographical space. Our analysis considered five eco-systems in the state of São Paulo. However, the analysis levels should consider eco-system agents locally and across regions and at the national level. Hence, we expect our contribution to inspire research on mutualistic symbiosis at different levels, scales, and contexts, improving our knowledge of eco-system bidirectional interactions.

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Appendix A. Topics included in the Research Protocol

Topic	Key references
Universities' Missions	Benneworth et al. (2017)
Role of TTOs	Siegel et al. (2003)
Organisational Structure	Siegel et al. (2003)
Content of Collaborations	Perkmann et al. (2013)
Flows of Financial Resources	D'Este & Perkmann (2011)
Intellectual Property Management	Murgia (2018)
Dynamics of Academic Entrepreneurship	Qian et al. (2013)
The attraction of Private Investment	Agrawal & Cockburn (2003)
Impact of Collaboration in Training and Research	Heaton et al. (2019)
Mediators of University-Industry Collaboration and Associated Outcomes	Sánchez-Barrioluengo & Benneworth (2019)
Opportunism vs. Collaboration	Bercovitz & Tyler (2014)
Institutional Context	Guerrero et al. (2019)

Source: Authors

Table 1. Universities' information (latest information available)

Universities / Research Institutes	Research Groups (2016)	Research Groups with Collaboration (2016)	Total of Collaborations (2016) ¹	Patents (2000-2017)	Research Granted by Fapesp (2019)
USP	1,811	599	3,125	779	1041
UNICAMP	743	245	1,212	929	404
UFSCAR	484	154	809	90	148
ITA	22	13	48	10	24
INPE	43	17	97	24	21
UFABC	101	38	170	22	73

Note: ¹ One limitation of this variable is that the data includes interactions with different types of actors. It is not possible to map only collaborations with firms.

Source: Authors

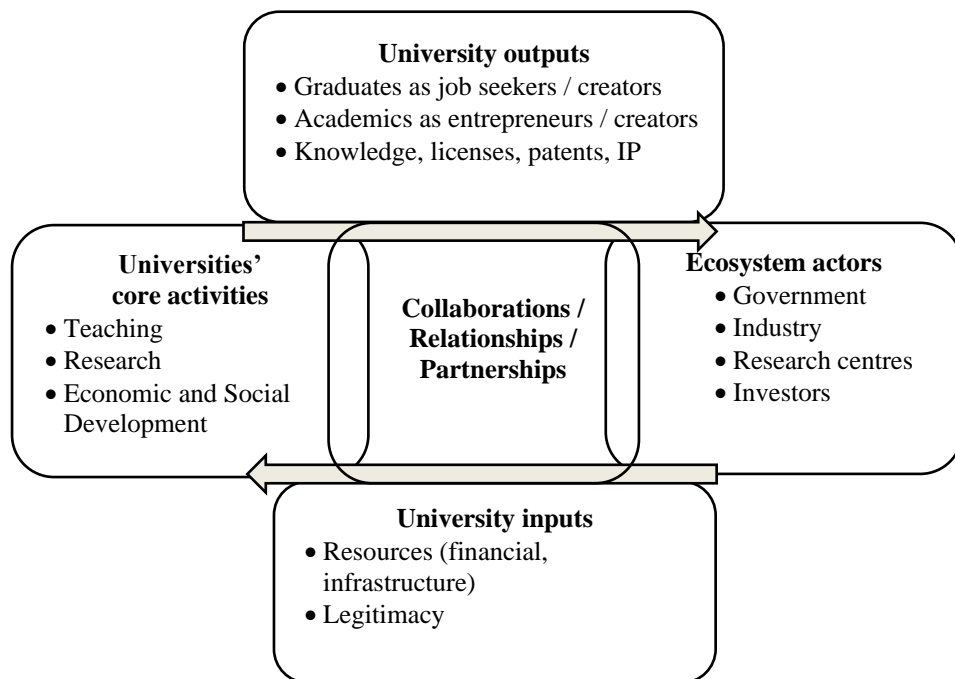
Table 2. Interviews' Information

Actor	Number of Actors	Number of Interviews	Ecosystems' Location (Number of Interviews)
TTOs ¹	5	6	Campinas(1), Ribeirão Preto(1), Santo André(2), São Carlos(1), São José dos Campos(1)
Research Groups	5	6	Campinas(2), Ribeirão Preto(1), São Carlos(1), São Paulo(1), São José dos Campos(1)
Research Centres	6	7	Campinas(3), Ribeirão Preto(1), São Carlos(1), São Paulo(1), São José dos Campos(1)
PIPE Companies	5	6	Campinas(1), Ribeirão Preto(1), São Carlos(2), São Paulo(1), São José dos Campos(1)

Note: ¹ No interview was conducted with the USP TTO in São Paulo, as the USP TTO unit in Ribeirão Preto follows the same innovation policy as the unit in São Paulo. Thus, the interview with the TTO deputy director in Ribeirão Preto has already encompassed an organizational perspective of all the activities performed by the office.

Source: Authors

Figure 1. Proposed conceptual framework



Source: Authors

Figure 2. Stages of Qualitative Data Aggregation

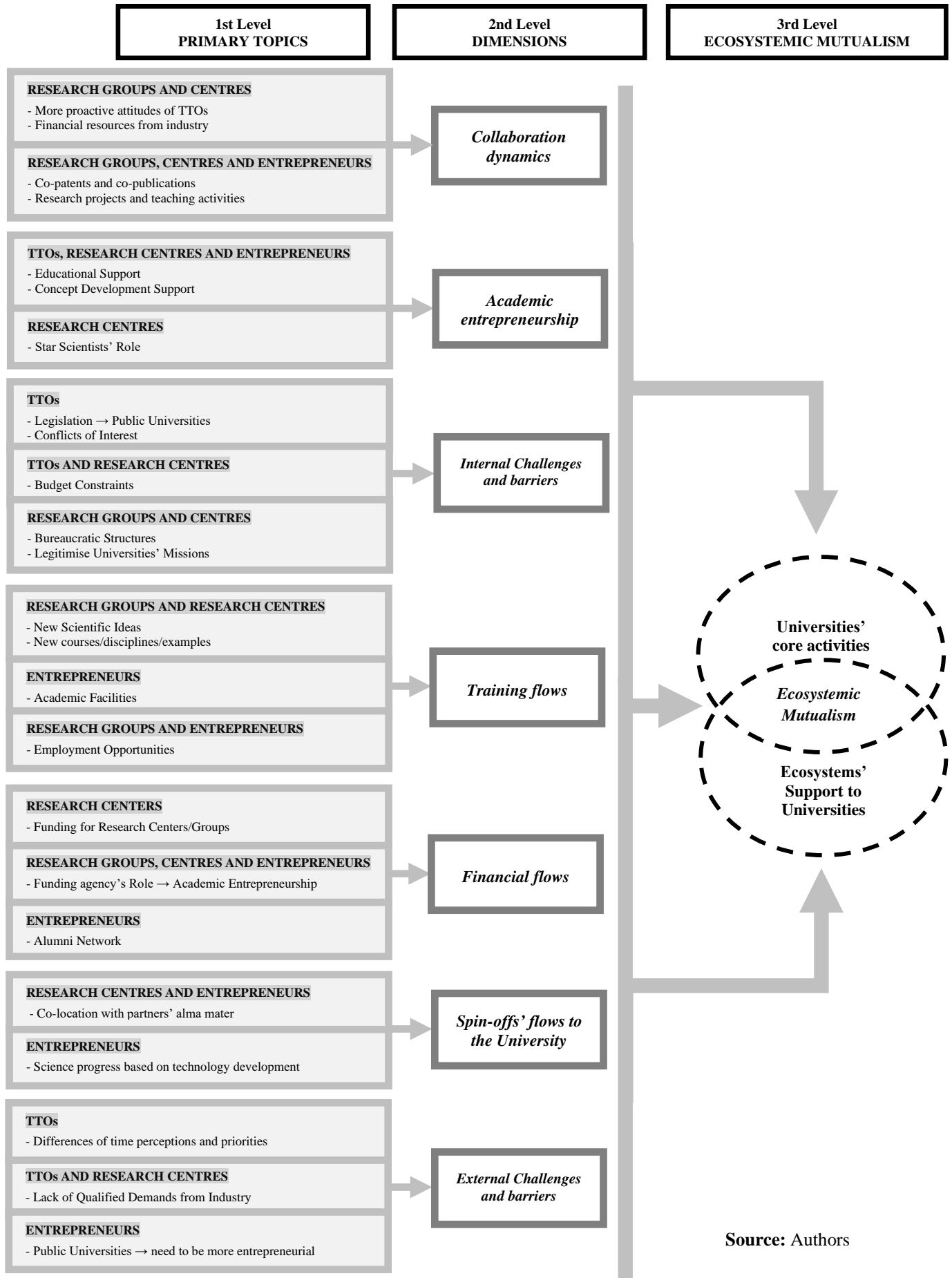
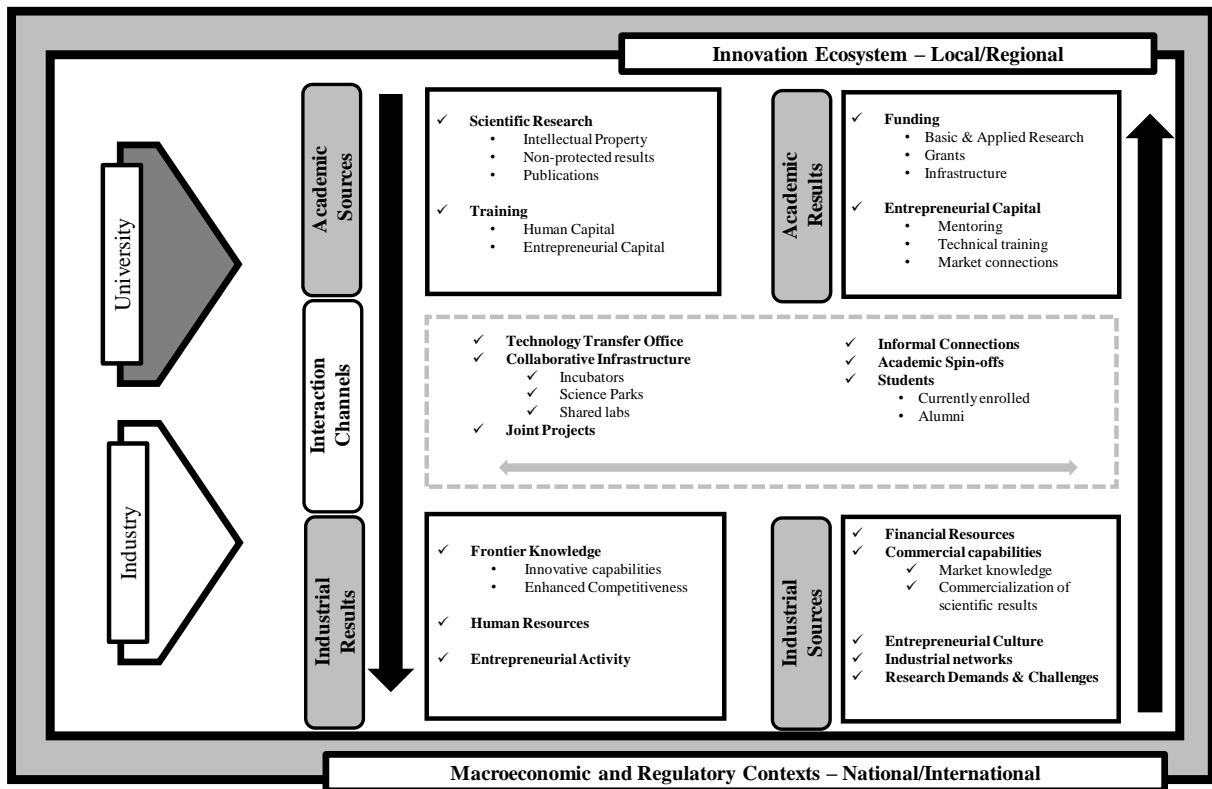


Figure 3. Dynamics of Collaboration in Different Ecosystem Levels



Source: Authors