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The university laboratory role for technology transfer to firms in Brazil: two case studies in Biotechnology

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Abstract: This paper analyzes the university laboratory's role in the university-industry interactions for technology transfer in biotechnology. Despite the importance of laboratory infrastructure for an entrepreneurial university and the development of new technologies, there are few studies focusing on this level of analysis. This study explores this literature gap with data from two leading laboratories in a high-ranked university in Brazil, the Federal University of Minas Gerais. This case study includes the application of two questionnaires to describe laboratory infrastructure and its firm collaboration, five interviews with laboratory leaders and key post-doc fellows, and documentary research. Results show that physical infrastructure, biological samples, and qualified people enabled technology transfer to firms. The channels of interaction between the laboratories and firms were identified. Spin-offs are a channel for technology transfer in the two laboratories, performing a bilateral hybrid function of disseminating university research results and brokering patent licensing to firms. Spin-offs also contribute to the absorptive capacity of other firms and, above all, allow laboratories to disclose results to the community and potential end-users. Findings present a new perspective on spin-off technology transfer in Brazil and in other developing countries.

Keywords: Entrepreneurial university; Technology transfer; Spin-off; Triple Helix; University-industry interaction.

O papel dos laboratórios universitários na transferência de tecnologia para empresas no Brasil: dois estudos de caso em Biotecnologia

resumo:
Este artigo analisa o papel do laboratório universitário nas interações universidade-empresa para transferência de tecnologia em biotecnologia. Apesar da importância da infraestrutura de laboratórios para a universidade empreendedora e o desenvolvimento de novas tecnologias, poucos são os estudos neste nível de análise. Explora-se neste artigo essa lacuna da literatura com dados de dois laboratórios em uma universidade de excelência no Brasil, a Universidade Federal de Minas Gerais. Contempla a aplicação de dois questionários para descrever a infraestrutura do laboratório e sua interação com empresas; cinco entrevistas com os líderes e pós-doutorandos dos laboratórios e pesquisa documental. Os resultados mostram que a infraestrutura física, as amostras biológicas e as pessoas qualificadas possibilitaram a transferência de tecnologia para empresas. Foram identificados os canais de interação dos laboratórios com as empresas. *Spin-off* foi um canal recorrente para a transferência de tecnologia nos dois laboratórios, com função bilateral de disseminar resultados de pesquisas universitárias e intermediar o licenciamento de patentes da universidade para as empresas. Os *spin-offs* criados pelos coordenadores dos laboratórios contribuíram para o aumento da capacidade de absorção de outras empresas e permitiram a divulgação dos resultados dos laboratórios universitários a comunidade e usuários das tecnologias. Apresenta-se uma nova perspectiva sobre a transferência de tecnologia no Brasil e em outros países em desenvolvimento.

palavras-chave: Universidade empreendedora; Transferência de tecnologia; Spin-off; Triple Helix; Interação universidade-empresa.

Código JEL: O38; O39.

1. Introduction

Scientific research conducted in university laboratories can generate new knowledge, technology and allow student training. In this sense, the university research laboratory is a space that takes on the challenge of translating part of the research carried out into practical application, supporting innovation by the productive sector (Reynolds and De Negri, 2017).

In the field of biotechnology, experiments on living cells and living beings demand high specialization of equipment, research inputs, and qualified people. Advances in university research results are reported to foster the economic growth of firms in biotechnology (Mcmillan et al., 2000; Cooke, 2002). For instance, the university's research results have been influencing the health care industry, by contributing to generate, evaluate, and introduce new medical devices such as surgical and medical instruments, dental equipment, supplies, navigational, measuring, electromedical, and control instruments (NAE, 2003). Basic academic advances in physics, materials sciences, optics, analytical methods, and computer science have resulted in many new medical device developments (NAE, 2003). The university research laboratories and firms interaction has been conceptualized in terms of university-industry interaction in the field of economics of innovation. Thus, for the introduction of products that are new to the market, partners from science are more important than the firms' customers (Kaufmann and Todtling, 2001).

University-industry interaction (UII) allows the transferring of knowledge and technology from university to firms (Zhang et al., 2018). UII is a strategic factor for fostering innovation and the development of the economy via the expansion of scientific knowledge (Mowery and Sampat, 2005; Albuquerque et al., 2005). It occurs through several channels, such as sponsored research, spin-off firms, patent licensing, and consultancies. To promote technology transfer from the university laboratory bench to the market, there are complex and diverse processes and interactive chains of transactions between scientists, entrepreneurs, and the government (Cooke, 2002; Etzkowitz, 2017).

It is noteworthy that most research investigates this interaction from the point of view of firms or universities informed by the Technology Transfer Office (TTO) and university dean (Klevorick et al., 1995; Albuquerque et al., 2015; Lemos and Cario, 2017). Nevertheless, these interactions are strongly dependent on decisions and dynamics at the level of university research laboratories. However, few studies have given attention to this level of analysis (Laredo and Mustar, 2000; Kleinman, 2003; NAE, 2003). To help fill in this gap, this study analyzes the perspective of university research laboratories in relation to their UII in a developing country context. This study was carried out in two research laboratories in Biotechnology at the Federal University of Minas Gerais (UFMG), a research university ranked the 5th in the Latin American region by The Times Higher Education; it stands out at the regional, and national levels for research quality, teaching excellence, and social and economic impacts. UFMG outstands in the local biotechnology cluster in the state and in Brazil (Torres-Freire et al., 2014).

The research question that guides this study is: *How do the university research laboratory infrastructure, human capital, and the local incentives influence the knowledge and technology transfer to biotechnology firms in the Brazilian context?*

2. University Research Laboratories and Biotechnology

During the 20th century, university research began to influence economic growth in a systematic way, following the science and technology evolution (Mowery and Rosenberg, 1998) and supporting the emergence of the knowledge-based economy (OECD, 2005). In some fields of knowledge, more specifically the new science-based technologies such as biotechnology, the university research laboratory gained industrial and governmental attention (Cooke, 2002). In Brazil, in the end of the 1980s, influenced by the United States, there was an attempt by the Brazilian government to approximate universities to the industry through policies for scientific knowledge transfer to the industrial sector (Velho et al., 2004). Various government initiatives have been aimed to promote Science Technology & Innovation (STI) in Brazil, since the late 1990s, such as infrastructure renewal, higher education careers regulation, financing for innovation, and the legislation to public-private partnerships (De Negri, 2017). However, these advances were reflected only in the growth of scientific indicators, such as numbers of worldwide publications, while the indicators of commercial applicability of research results, such as the rate of technological innovation, patent granted, and transferred did not follow this growth (De Negri, 2017).

Fostering biotechnology capabilities has been one of the central tenets of the Brazilian STI policies since early 1990, however, these capabilities have not been translated into a more complex productive structure, at least not to a degree comparable to scientific development (Cassiolato et al., 2011; De Negri, 2017). The technological innovation unit at a university is the research laboratory, a space with specialized human capital and instruments to enable experimenting and potential technology development (De Negri and Squeff, 2016).

The literature presents mainly technical and sociological definitions of a university research laboratory. According to Latour and Woolgar (1986), a research laboratory is constantly conducting experiments in a safe way under propositions: adding modalities, quoting, increasing, decreasing, and combining. For Knorr-Cetina (1981), a laboratory is a geographically limited space, with an accumulation of instruments and devices within a working space composed of chairs, tables, drawers, shelves, utensils, refrigerators, freezers, labeled samples, and source-materials. A research laboratory is a place to validate and experiment, based on theories and methodologies (Tash, 2006), and explains and interprets what happened, what is the case, how to make sense of it (Knorr-Cetina, 1981). Moreover, the laboratory physical installations are an important place for students and researchers to practice what they have learned in theory (De Negri, 2017).

The research laboratory is highly specialized place, including research equipment and materials, an intense experimentation cycle to validate codified knowledge, and the presence of internal and external researchers developing science through the scientific method (Tash, 2006). Several factors can influence the results of a research laboratory, with human resources, that is, people who are directly linked to research activities in the laboratory, standing out for the human capital that they bring in (Etzkowitz and Kemelgor, 1998). Human capital is conceptualized as the knowledge of individuals put into practice through skills necessary to work in a firm or organization and includes formal training and competencies (Dantas et al., 2007). In a research laboratory, human resources are highly qualified, and the experience gained in the workplace is essential for carrying out experiments in accordance with methodological procedures.

In a university research laboratory, there is collaboration, diversity, high educational level, interest in the search for knowledge, openness to new paradigms, and high turnover of students and researchers (Tash, 2006). Academic research groups are composed in order to achieve the research objectives with complementary knowledge and skills to provide different perspectives and communication networks (Verbree et al., 2013; Hülsheger et al., 2009). This heterogeneity can be related to functional areas, research methods, educational specialization, experience, age, and gender (Carayol; Matt, 2004, Verbree et al., 2013).

More specifically in biotechnology, access to equipment is needed to explore living organisms, considering regulatory requirements to conduct strict research at different stages, such as pre-clinical and clinical tests, which are time-consuming and input expensive (Peerbaye and Mangematin, 2005). Biotechnology has emerged as a relevant market, and it is considered relevant for human development, with a strong social, environmental, and economic impact on society (Cooke, 2002; Cassiolato et al., 2011). Biotechnology offers an unprecedented opportunity for developing countries, however, harnessing this opportunity depends essentially on the creation of capacities that go beyond laboratory infrastructure and include access to knowledge under the protection of intellectual property, innovative applications, and entrepreneurship skills (Lokko et al., 2018).

3. Triple Helix and the Entrepreneurial University

The Triple Helix (TH) articulates three spheres - university, industry, and government – and their distinct functions: a) teaching and researching, b) generation of wealth and innovative products, and c) normative control and policy regulation (Etzkowitz and Leydesdorff, 2000). TH spheres have porous boundaries when interacting, one taking the role of the other, laterally, bottom-up, and top-down (Etzkowitz and Leydesdorff, 2000; Etzkowitz and Klofsten, 2005).

The emerging role of the university as a source of firms is complemented by the role of government, who provides resources for academic research and drives the demand, as a customer (Etzkowitz and Zhou, 2017) or an enabler. In these interactions, universities are important to the creation of knowledge-based firms, since they have a critical mass of scientists and other resources such as equipment.

The knowledge-based firms' or technological spin-offs' formation is a result of inputs from multiple sources. Some enabling conditions are access to a critical mass of scientists, and the availability of seed capital and equipment, among others (See Figure 1) .

Figure 1 - Triple Helix conditions for spin-offs and knowledge-firm creation

Factor	Description
Human Capital	1. A critical mass of scientists, engineers linked through social networks. 2. Existence of research groups in areas of potential commercialization. 3. A pool of scientists and engineers interested in forming their own firms.
Material	4. Availability of seed capital. 5. Inexpensive and appropriate space for new firms. 6. Equipment, ranging from multi-media computers to prototype biotechnology plants.
Organizational	7. Opportunities for scientists and engineers to learn business skills or gain access to persons with these skills. 8. University policies designed to a) encourage faculty members and students to interact with industry, b) give academic credit toward promotion and degrees for this work, and c) provide clear guidelines delineating appropriate activities. 9. Applied research institutes, centers, and incubator facilities to provide linkages between academic scientists and engineers and industry. 10. A residential community with cultural, scenic, recreational resources that can attract and hold a population whose skills make them potentially highly mobile.

Source: Etzkowitz, 2008, p.84

A spin-off is a new firm that is formed by individuals who were former employees of a parent organization, and with a core technology that is transferred from a parent organization (Rogers and Steffensen, 1999). A spin-off is a technology transfer mechanism because it is usually formed in order to commercialize a technology that originated in a university research center, in a private Research and Development (R&D) organization, or a government R&D laboratory (Rogers et al., 2001). Technology transfer is the application of information or technological innovation into use (Gibson and Rogers, 1994). The technology transfer process usually involves moving a technological innovation from an R&D organization to a receptor organization such as a firm. Technological innovation is considered fully transferred when it is commercialized as a product that is sold in the marketplace (Rogers et al., 2001). Technology transfer involves a broader set of competencies: selective, organizational, technical and learning, entrepreneurial, societal, cultural, and policy (Ranga and Etzkowitz, 2013).

Research universities play an increasingly important role in technology transfer and are generally considered to be effective in transferring technology (Rogers et al., 2001), which makes them entrepreneurial universities. The key elements of an entrepreneurial university are expressed in five norms: a) Knowledge spilled-over, b) Hybridization, c) Research units as quasi-firms, d)

Entrepreneurial culture, and e) Reflexivity as interdependent university-industry-government (Etzkowitz, 2008; Etzkowitz and Zhou, 2017).

Knowledge spillover occurs when information and knowledge generate additional opportunities for application in other settings and are geographically localized (Jaffe et al., 1993). The transfer of tacit knowledge, which includes knowledge that is either impossible or costly to codify, generally requires direct interaction: in person, by phone, or through written correspondence (Agrawal, 2001).

Related to the hybridization, one of the main objectives of the TH movement is to create some hybrid structures, which are able to relate with industry and university or industry and government, such as TTO, business incubators, start-up accelerators, and venture capital (Etzkowitz, 2008). These intermediary hybrid structures facilitate communication between different actors and the capitalization of knowledge (Ranga and Etzkowitz, 2013). In the early 2000s, the Brazilian Innovation Law instituted the Technological Innovation Centers or TTO in universities to facilitate and liaise the interface between them and the productive sector (Brasil, 2004). Although Brazilian CT&I policies and the innovation law foresaw university-industry interaction for innovation, they can be considered as an initial stage, since they failed to some extent, being unable yet to provide legal certainty, encourage interactions and give dynamism to the components of the national innovation system (De Negri, 2017).

Regarding research units as quasi-firms is related to the capacity of the group research to organize within the university, as potential entrepreneurial teams, with invention partners, and commercial partners (Etzkowitz, 2008). In this sense, is observed the integration of academic and business elements into new hybrid formats such as university-industry research centers (Etzkowitz and Zhou, 2017).

The entrepreneurial culture spread all over the university campus can be noted when students and professors have ambition also in the commercial exploitation of academic results. It’s a willingness to use scientific knowledge to change the world, by translating tacit academic knowledge into explicit knowledge or technology (Etzkowitz and Zhou, 2017). There is a level of academic entrepreneurial transformation differentiation between countries considering degrees of state control and levels of a university initiative (Etzkowitz et. al., 2008).

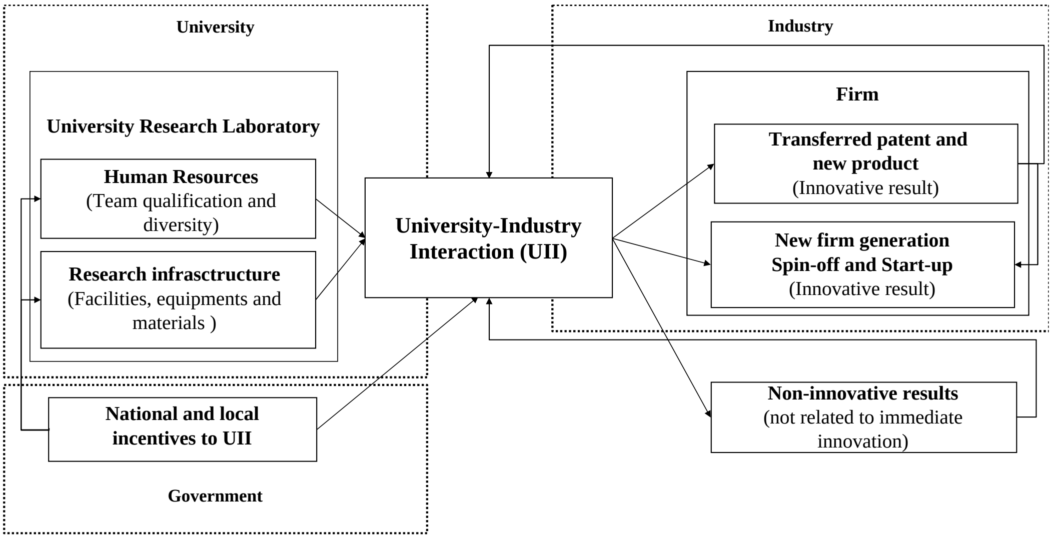
Finally, the entrepreneurial university element of reflexivity is related to the continuum flow of student renovation, which brings to the internal structure of the university mobility and interconnectivity between university-industry-government, since the university students can be current or potential industry workforce. This university advantage is related to knowledge renovation, facilitating further development of useful findings and pull across institutional boundaries (Etzkowitz, 2008).

Research carried out in developing countries investigated the TH model observed distinctions from developed countries (Etzkowitz and Dzisah, 2008; Kruss, 2008). Some of the differences are that developing countries show late industrialization, lack of industry R&D activities, and recent support infrastructure to entrepreneurship. Their trajectory of economic development has been strongly shaped by the imperatives of state security, energy sufficiency, import-substitution, and fragmentation of STI policies (Kruss, 2008).

4. Analytical Framework

Based on the literature review we propose an analytical framework (Figure 2) to guide us in understanding the internal organization of knowledge transfer from university to firms.

Figure 2 - Analytical framework.



Source: Translated from Liboreiro, 2020.

The selected factors presented in our analytical framework: Human capital for research, Physical infrastructure, Local and national incentives for UII, Innovative results: Patent and new product, Innovative results: new spin-off, start-up, and Non-immediate innovative results are conceptualized and described in Figure 3.

Figure 3 - Conceptual Description of university-industry interaction analysis.

Helix	Factor/ Construct	Concept/ Description	Authors
University	Human capital for research	Researchers' qualification and educational diversity. Research experience. Critical mass.	Cunningham et al., 2014 De Negri, et al., 2013. Etzkowitz, 2008
University	Physical infrastructure	Equipment, materials, and research inputs. Infrastructure scarcity may impose limitations to experiments and technological outdatedness, compromising the quality of research analysis.	Bonaccorsi and Piccaluga,1994 De Negri and Squeff, 2016 Etzkowitz, 2008
Government	Local and national incentives for UII	Funding sources available, innovation laws, and other regulations. The financial system, the industrial and technological structure, governmental support, educational systems, access to resources, and technological policies.	Meyer-Krahmer and Schmoch, 1998. Nelson, 1993 Albuquerque, 1996 Etzkowitz, 2008 Cassiolato et al., 2011
Industry	Innovative results: Patent and new product	These results originate from university-industry interaction, such as patent transfers, new products, and services.	Dutrenit and Arza, 2010 Albuquerque et al., 2015. Schmoch, 1999
Industry	Innovative results: new spin-off, start-up	Also originated from university-industry interaction, such as new firm generation - spin-off or start-up.	Etzkowitz, 2008 Cooke, 2002 Cozzi et al., 2008
University, Industry	Non-immediate innovative results	Other relevant results, such as learning and networking, work experience, reports.	Bonaccorsi and Piccaluga, 1994, Burcharth, 2011

Source: Own source, based on Liboreiro, 2020

The description of the investigated constructs facilitates understanding how to measure them, considering for example traditional measurements, such as researcher's formal education, the number of patents filed, granted, and transferred to firms, and public funding obtained.

5. Methodology and selection of cases

This research uses a descriptive case study method, combining quantitative and qualitative data sources, and a narrative approach to triangulate the analysis. This case study includes a) the application of two questionnaires to describe each laboratory infrastructure and its collaboration with firms; b) five interviews with laboratory leaders and key post-doc fellows engaged in interactions with industry and c) documentary research.

We selected two biotechnology research laboratories at a leading Brazilian university, the Federal University of Minas Gerais (UFMG). This university was selected by its regional and national outstanding position in providing research and teaching excellence, and promoting social and economic impacts, through prominent biotechnology laboratories that establish relationships with firms (Torres-Freire et al., 2014). This analysis of two cases allowed a deeper understanding of the characteristics of university-industry interaction in Brazil, a country considered in an intermediate stage of entrepreneurial university culture (Etzkowitz et. al., 2008).

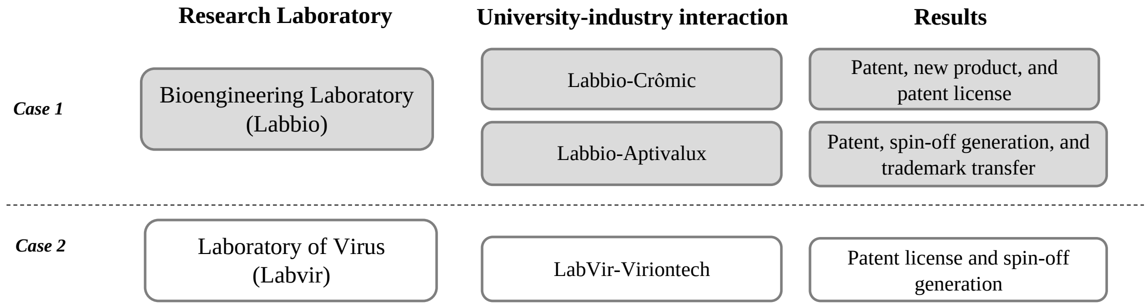
The selection of the two university laboratories applied the following criteria: a) field of research related to applied sciences and life sciences, such as bioengineering and microbiology, b) relationships between the laboratory and firms for technological transfer and c) interest and availability of the laboratory coordinator in participating in this research.

Primary data collection instruments included two structured questionnaires, which protocols were validated in previous studies, and a semi-structured interview guide. The first questionnaire, BR Survey, contained 17 questions on the following topics: Interaction with firms: channels, benefits, and results (9 questions), and Research group technological results information (8 questions), plus 5 laboratory characterization questions (Albuquerque et al., 2015). Information requested dates back to three years (Suzigan et al., 2009). It was validated in 12 Southern countries by Albuquerque et. al. (2015), within the scope of the Research on Knowledge Systems (RoKS) project. In Brazil, the BR Survey questionnaire was validated with more than 2,000 research groups in public institutions and more than 1,800 firms. The second questionnaire, Ipea-Infra, contained 20 questions on laboratory infrastructure (3 questions), laboratory-firm cooperation (2 questions), laboratory capacity (3 questions), modernization and repair of equipment (2 questions), laboratory services, and use of equipment by external users (2 questions), equipment values, costs and revenues (7 questions), and relevant equipment (1 question). It was validated by De Negri and Squeff (2016), in a study with 2,000 Brazilian research groups and laboratories in 2013. It requests information for the last year of university research laboratory activities (De Negri and Squeff, 2016). BR Survey and Ipea-Infra questionnaires were responded by each laboratory coordinator. The semi-structured interview guide contained 13 questions, covering the following themes: laboratory and team characteristics, UII channels, UII incentives, UII results, and UII enablers, benefits, and barriers. Interviews were conducted through scheduled face-to-face meetings with laboratory coordinators and post-doc affiliated researchers fellows between July and August 2019, totaling five researchers. Interviewees were anonymized as E1, E2, E3, E4, and E5.

We selected and analyzed documentary materials related to the two laboratories' technology transfer. Data from UFMG's TTO, the Technological Transfer and Innovation Coordination (CTIT), technology transfer report, university and laboratory's websites, patent database from the Brazilian National Institute of Industrial Property (INPI), and governmental information on calls for sponsorship for university-industry collaboration for innovation released by Financing Agency for Studies and Projects (FINEPE), Minas Gerais State Research Support Foundation (FAPEMIG), National Council for Scientific and Technological Development (CNPq), among others State funding institutions.

Findings are organized according to the analytical framework illustrated in Figure 4.

Figure 4 - Results presentation structure.



Source: Own source

6. Results

This section starts with the overall findings and then presents the in-depth description and analysis of each interaction. The investigated laboratories are well-structured and have been interacting with firms for knowledge and technology transfer for over 20 years. For this study, we analyzed three university-industry interactions (UII) deemed by the laboratory coordinators as relevant experiences to showcase the laboratory internal organization to engage in interactions.

Labbio (Case 1) is a bioengineering laboratory founded in 1999, located in the Mechanical Engineering Department of the UFMG. Labbio is dedicated to research in cardiovascular engineering, assistive technologies, biomimetics, regenerative medicine, biomechanics, and neurological vision. This laboratory has three spin-offs. Labvir (Case 2) is a laboratory of virus founded in 1962, and is one of the largest and most traditional virology laboratories in Brazil and Latin America. It is in the Department of Microbiology and holds the prestigious status of a National Institute of Science and Technology (INCT), with its INCT for Emerging and Reemerging Viral Diseases. Its modern infrastructure allows the characterization of viral agents in human and veterinary environments. This laboratory has one spin-off. Figure 5 summarizes some UFMG laboratories key characteristics.

Figure 5 - Infrastructure, Human Resources, and UII Channels.

	Case 1 - Labbio	**Case 2 - Labvir**
1.Research area (m^2)	200m^2	320m^2
2. Total human resources Undergraduates Master students PhD students Postdoc students and above	42 14 (33%) 14 (33%) 10 (24%) 4 (10%)	44 17 (38%) 10 (23%) 10 (23%) 7 (16%)
2. Human Resources Researcher training	Mechanical Engineering, Veterinary Medicine, Medicine, Dentistry, Physiotherapy, Biology, Chemical Engineering, Electrical Engineering, and Automation Engineering.	Biochemistry, Pharmacy, Biological Sciences, Biology, Biomedicine, Medicine.
3. Equipment value in 2018[1]	Above USD 65 K to USD 130 K	Above USD 261 K to USD 522 K
4. 2018 Revenue	USD 48 K	USD 183 K
5. Patents	51 (46 national; 5 international)	54 (28 national; 26 international)
6.University-industry interaction channels for knowledge transfer	1. Congress and Conference 2. Business incubator 3. Publications	1. Publications 2.Temporary professional's exchange

[1] The Brazilian Real conversion rate to the US dollar on the data collection (July 2019) was 1 BRA = 0.261 US$.

	4.Temporary professional's exchange 5. Technology licensing 6. Cooperative R&D project 7. Informal exchange of information 8. Consulting	3. Technology licensing 4. Cooperative R&D project 5. Training 6. Consulting

Source: Own source. Research data using Ipea-Infra and BR-Survey questionnaires.

Figure 6 presents the characteristics of the main firms that had relationships with these laboratories (Labbio and Labvir). It is noteworthy that more than one firm can be involved in the same stream of interactions to transfer a certain technology to the market, as the subsections will show.

Figure 6 - Characteristics of firms that interact with the selected laboratories

	Firm	Since	Industry	Activities	Size
Labbio	Crômic	1993	Footwear	Footwear production	Small
	Toshiba and Toshiba South America	1932; 1968	Electronic and energy	Energy and electrical infrastructure, devices, and components.	Large
	Aptivalux Bioengenharia	2004	Biotechnology	Phototherapy. Consultancy.	Micro
	Hypofarma	1948	Pharmaceutical	Production of injectable drugs.	Medium
	DMC	1998	Health equipment	Photoactivation devices for tooth whitening and laser therapy.	Medium
Labvir	Bioclin	1977	Health diagnosis	Reagents; Disease diagnostic kit.	Medium
	Viriontech Biotecnologia	2004	Health diagnosis	Training for Biotech firms; Disease diagnostic kits.	Micro

Source: Own source. Research data.

A summary of the three key laboratory interactions with firms, based on the TH model and our analytical framework, is presented in Figure 7.

Figure 7 - Description of the university research laboratories' interactions with firms

Feature/ Analysis variable	**UFMG's Laboratory Labbio**		**UFMG's Laboratory Labvir**
University-industry interaction duration	• Labbio and Crômic • (2007-2012, 5 years)	• Labbio and Aptivalux • (2004-2019, 15 years)	• Labvir and Viriontech • (2004-2019, 15 years)
Entrepreneurial university	TTO - Patent licensed through CTIT.	Entrepreneurial research group as a quasi-firm.	TTO - Patent licensed through CTIT.
New TH functions assumed by each sphere in the university-industry interaction	• University supported the product announcement, marketing, and sales at UFMG campuses. • Government-funded research of industrial interest through financing the university laboratory.	• Spin-off assumed the role of the university disseminating lab technologies to larger firms. • Government-funded research of industrial interest through financing the university laboratory.	• Spin-off assumed the role of the university by intermediating and supporting the technology transfer process to larger firms during the patent licensing.
Human capital HR qualification: formal training.	• 11 Researchers • Mechanical Engineering (1 undergraduate, 4 masters, 5 Ph.D.) • Physiotherapy Specialist (1) • Rehabilitation Sciences (4 masters, 1 Ph.D.) • Orthopedics and Sports specialist (1) • Intellectual Property Post-Doc (1) • Computer Science Master (1)	• 5 Researchers • Mechanical Engineering (2 masters, 2 Ph.D., 2 postdocs) • Biological Sciences (1 master, 1 Ph.D.) • Master of Dentistry (1) • Prothesis, Periodontics, and Implantology specialist (1)	• 7 Researchers • Pharmacy and Biochemistry (4 undergraduate) • Medicine (1) • Microbiology (1 undergraduate, 4 masters, 5 doctors, 3 Ph.D. Students, 4 post-docs) • Veterinary Medicine (1 undergraduate, 2 masters, 2 Ph.D.) • Ph.D. in Biochemistry (1)
National and local incentives to UII	• USD 15 K – RETEC/AMITEC by FAPEMIG (state agency) • USD 7,5 K – Crômic (firm) • 67% public and 33% private	• USD 150 K– FAPEMIG (state agency) • USD 400 K – FINEP (federal agency) • 100% public	• Source of incentives not informed. • 100% public.
Proximity levels of UII channels for knowledge transfer, articulation, and communication (Perkmann &Walsh, 2007).	• High:R&D partnerships, services, contracts. • Medium: Human resources training. • Low: Intellectual property transfer, publication.	• High: R&D partnerships, services, contracts. • Medium: Academic Entrepreneurship (spin-off generation); HR training. • Low: Intellectual property transfer, publication.	• High: R&D partnerships, services, contracts. • Medium: Academic entrepreneurship (spin-off generation); Human resources training. • Low: Intellectual property transfer, publication.
UII Results	• New product • HR Training • Theses and dissertations • Patent deposited at INPI • Financial Resources (Royalties) • Patent transferred	• New product • HR Training • Theses and dissertations • Patent deposited at INPI • Financial resources • Publications	• HR Training • Publications • Research visibility

Source: Own source. Research data.

6.1. Case 1 - Labbio Research Laboratory

This section presents the internal organization of Labbio (Figure 8) and details its two UII. These findings are from interviews' data, except when indicated otherwise.

Figure 8 - Labbio's internal organization

Human capital	- Hierarchy: coordinators, professors, postdocs, doctorates, masters, undergraduates. - On-the-job training in research broad-based technological areas. - Multidisciplinary teams organized by a research project based on needed competencies - Collaboration and Teamwork. - Weekly meetings for project follow-up. - Support for young researchers to write projects for government funding calls. - Experienced professors in writing research proposals for government funding calls. - Broad experience in writing national and international patents. - Experience with the patent license (6) and trademark license (1) processes. - Lab coordinator working time distribution: 30% research, 15% teaching, 40% interacting with firms, 25% administrative work (source: BR Survey). - Two administrative staff working in project management. - Lab coordinators were interested in generating products and interacting with firms. - Relationship with government sponsors for research: FINEP, FAPEMIG, and CNPq.
Physical infrastructure	- Most equipment was paid with public resources: 3D printers, prototyping materials, inputs. - Research inputs and equipment are imported from other countries. - Availability of other laboratories at UFMG upon a partnership between lab leaders. - Some equipment and research inputs were donated by companies. - Laboratory open to external users upon request to the coordinator (source: Ipea-Infra)
Entrepreneurial university	- Capitalization of knowledge (Patent licensing). - Interdependence with industry and government (Public and private research funding). - Independence from the university to organize itself as a quasi-firm (lab spin-off generation). - Hybridization of new organizational formats (TTO). - Reflexivity and renewal of the university's internal structure (new arrangement). - UFMG Business Incubator for students interested in starting a new business.
Transfer process	- Patent licensing, trademark licensing, R&D with hospitals, consultancy.
Internal Knowledge transfer process	- Technical knowledge transferred to students at the lab through research projects. - Collaboration and collective learning of students and researchers in research projects. - Personnel and students' training in how to use the equipment and create prototypes. - Joint R&D with the Pharmacy Department at UFMG – Mask research project.

Source: Own source. Research data.

These internal characteristics are embedded in a context of enablers and barriers to UII reported by Labbio's coordinator, as summarized in Figure 9 .

Figure 9 - Enablers and barriers to UII in Labbio.

Enablers to UII	- External Knowledge transfer process: o Science fairs and events disseminate the laboratory research results. o Firms visit for learning and students visit firms for exchange of knowledge and internships. o Searching and reaching out to potential client firms and advertising the laboratory technologies directly. o The laboratory spin-off, Aptivalux, disseminates new knowledge, results of lab research, and spreads the technologies to other firms. - National and local incentives to UII: o Government calls to fund joint research projects. o Location in the second biggest biotechnology hub in Brazil. o FINEP (federal funding agency) calls to fund biotechnology R&D. - CTIT seeks partnerships with the industry for technology transfer, preparing licensing contracts, and managing the royalties' payments. - CTIT teaches researchers how to draft and file patent applications and trademarks.
Barriers to UII	- Multiple levels and instances for contract approval. - Time consumed approving sponsored research within the university. - Time consumed in elaborating reports for sponsored research. - The lack of administrative support staff in the laboratory - The lack of biotechnology specialist at CTIT for translating the lab technologies to firms

Source: Own source. Research data.

Together, the internal organization and the contextual factors influence how the knowledge and technology transfer process occurs at Labbio. Two interactions, one with the firm Crômic and another with the spin-off Aptivalux, will be presented next, aiming at describing this process in detail.

6.1.1. Labbio - Crômic interaction: patent filed, patent licensed, and new product

Crômic is a firm from the footwear sector based in Nova Serrana city, at Minas Gerais State. In 2007, facing difficulties to innovate, Crômic sought the Federation of Industries of the State of Minas Gerais (FIEMG) for support in new technologies for product development. FIEMG forwarded the demand to the UFMG, via CTIT, which redirected it to Labbio.

The main events of this 6-year UII (2007-2012) are listed in Figure 10.

Figure 10 - Chronology of the Labbio-Crômic interaction

2007 - Crômic seeks out FIEMG, which forwards the firm demands to UFMG.
2007 - Signature of the Technical cooperation agreement between UFMG and Crômic and RETEC-AMITEC - nº RETMG 2007/005. Access to public funding, R$ 30,000 (FAPEMIG).
2008 - Labbio researchers develop a cushioning system for Crômic sneakers.
2008 – The new technology generated a UFMG Patent deposit at INPI, nº PI 0800552-4.
2008 - Signature of the Technology transfer contract nº 03/2008, UFMG’s patent licensed to Crômic.
2009 – Crômic starts the sales of the sneakers, including a partnership with a shop at UFMG campuses in Belo Horizonte city.
2012 - Labbio researchers propose new developments to the sneakers project. Crômic refuses the proposal because it will stop producing sneakers.

Source: Own source. Research data.

One of the reasons that led FIEMG to direct Crômic's demand to UFMG and Labbio was the expertise of the principal investigator and laboratory coordinator, according to E2. E1 states that CTIT's infrastructure contributed to the beginning of this relationship between Crômic and Labbio. E1 and E2 participated in this project from the start and have their names in the patent generated.

In the first year of the interaction, 2007, the prototype of the cushioning system for the sole of the Aerobase model was built. The interaction involved qualified researchers from various departments and knowledge areas. Tests were carried out to validate the prototype.

In 2008, CTIT brokered the signing of the transfer contract nº. 03/2008, whereby UFMG transferred to Crômic the patent rights for 10 years (Oliveira and Giroletti, 2016). Crômic paid UFMG 1.5% of the gross revenue earned as royalties from product sales. In 2012, Labbio researchers suggested new developments to the sneakers. However, Crômic had no interest in continuing the UII, as its sneakers’ production line was discontinued in 2013.

6.1.2. Labbio - Aptivalux interaction: patent filed, spin-off and trademark transfer

The Aptivalux Bioengineering firm was created in 2004, as the result of research carried out in Labbio. It focuses on products in photobiomodulation, photodynamic therapy, tooth whitening, mucositis, periodontics, and disinfection of attacks by bacteria or fungi activated by light. Aptivalux was formed by three dentists, one veterinarian, and one mechanical engineer.

The main events of this 15-year UII (2004-2019) are listed in Figure 11.

Figure 11 - Chronology of the Labbio-Aptivalux interaction.

2000 - Labbio received inputs donation from the firm Toshiba (2000 – 2005).
2004 – Creation of Aptivalux by five Labbio researchers.
2005 - Technological consultancies to other firms (2005 - 2016).
2006 - Signature of the 5-year patent licensing contract with Hypofarma via Euvaldo Lodi - FIEMG and FAPEMIG.
2008 - Deposit of the Chimiolux trademark at INPI.
2010 – Trademark granted, nº 829624210, Chimiolux®, by INPI.
2011 - Curcumin patent deposit at INPI, nº BR-PI1102594-A2.
2013 – Chimiolux® trademark is licensed to the firm DMC by Aptivalux.
2016 - Death of one of the Aptivalux's founders, professor and principal investigator at Labbio.
2019 - Closing of Aptivalux.

Source: Own source. Research data.

Aptivalux's initial objective was to build LED laser radiation equipment. LED input was donated by Toshiba to Labbio and Aptivalux. During the development process, Aptivalux found out that the investment to set up a factory would be prohibitive, and the many regulations by the National Health Surveillance Agency (ANVISA) to obtain the operating license represented a critical barrier. Aptivalux’s founders, then, searched for a partner with the needed infrastructure and ANVISA certifications. The researchers visited many firms and the Euvaldo Lodi Institute - FIEMG, to get to know other potential partners. The first technology transfer was in 2006 to Hypofarma, who produced and sold the Chimiolux product for five years. At the end of this contract, given the lack of interest of Hypofarma to renew it, Aptivalux’s founders found a new partner at DMC Equipment, to whom they licensed the trademark Chimiolux®.

Aptivalux continued to carry out technological consulting services, which revenues helped the maintenance of some of the Labbio’s research and which expansion amplified the spin-off’s networking with other firms. Labbio and Aptivalux invested time and financial resources in this knowledge transfer strategy to expand the access of other firms to knowledge about new technologies, hoping that this could contribute to creating a market of potential buyers.

In this process, Labbio and Aptivalux were granted USD 400,000 in research funding by FINEP. It was a complex process, time-consuming for proposal writing and accountability reporting (E3). They were also granted USD 150,000 by FAPEMIG, which allowed the acquisition of equipment to Labbio in 2009 , according to E3.

In 2016, the founder of Labbio and a key Aptivalux’s partner died. After this critical and unexpected event, there was a fall in the firm's income, which caused the firm to close in 2019.

6.2. Case 2 - Labvir Research Laboratory

This section presents the UII at Labvir. Figure 12 presents the internal organization of this laboratory, according to interviews’ data, except when indicated otherwise.

Figure 12 - Labvir’s internal organization

Human Resources	- Entry-level requirement: formal training in biological sciences and health. - Multidisciplinary team defined per project, including biologists, pharmacists, biomedicals. - Collaboration and teamwork. - Students play a key role in research with biological material and in asking research questions. - Five leading professors, experts in virology, human health, veterinary medicine, epidemiology, and evolution. - On-the-job training in research and on how to use equipment safely. - Broad experience in writing patents and filing them nationally (28) and internationally (26). - Experience in writing research projects for governmental funding calls. - Lab coordinator working time distribution: 40% research, 33% teaching, and 37% administrative work (source: BR Survey). - Lab coordinators interested in generating products and in interacting with firms. - Relationship with government sponsors for research projects: FINEP, FAPEMIG, CNPq.
Physical infrastructure	- The laboratory has Biosafety levels 1 and 2. - Availability of biological sample collections obtained on special epidemiological terms. - All equipment was acquired with public resources. - Equipment rooms: thermal cyclers that perform PCR in a real-time, ultracentrifuge, etc. - Received a few research inputs through donations by companies. - Laboratory open to external users upon request to the coordinator (source: Ipea-Infra).
Entrepreneurial university	- Capitalization of knowledge (Patent licensing). - Interdependence with industry and government (Public and private research funding). - Independence from the university to organize itself as a quasi-firm (lab spin-off generation). - Hybridization of new organizational formats (TTO – CTIT). - Reflexivity and renewal of the university's internal structure (new arrangement).
Transference	- Patent licensing, trademark licensing, R&D with hospitals.
Internal Knowledge transfer	- Technical knowledge from professors transferred to students at the lab through research. - Students’ collaboration in research projects. - Graduate student researchers leading projects. - Personnel and students’ training in how to use the equipment and create prototypes. - CTIT teaches researchers how to draft and file patent applications and trademarks.

Source: Own source. Research data.

These internal characteristics are embedded in a context of enablers and barriers to UII reported by Labvir's coordinator, as summarized in Figure 13.

Figure 13 - Enablers and Barriers of UII in Labvir

Enablers to UII	- External Knowledge transfer process: o Labvir is an INCT (CNPq-INCT) with leadership in knowledge nucleation for other graduate programs and research groups. o The greatest virologists who are on the rise in Brazil today were trained at Labvir. o Science fairs and events disseminate the laboratory research results. o Firms visit the laboratory for learning and students visit firms for exchange of knowledge and internships. o Searching and reaching out to potential client firms and advertising the laboratory technologies directly. o The laboratory spin-off, Aptivalux, disseminates new knowledge, results of lab research, and spreads the technologies to other firms. - National and local incentives to UII: o Government calls to fund joint research projects. o Location in the second biggest biotechnology hub in Brazil. o Partnerships with the Ministry of Agriculture and the Brazilian Agricultural Research Corporation (Embrapa) o Biominas Foundation, a local biotechnology business incubator in Belo Horizonte. - CTIT seeks partnerships with the industry for technology transfer, helps in preparing licensing contracts, and managing the royalties' payments. - CTIT teaches researchers how to draft and file patent applications and trademarks.
Barriers to UII	- Multiple levels and departments for the university approval of sponsored research. - Lack of communication between the TTO - CTIT and the UFMG's Research Development Foundation (FUNDEP) for sponsored research. - Time consumed in university instances for sponsored research contract approval. - The lack of administrative support staff in the laboratory. - The lack of interest of the Brazilian firms at regional and national levels.

Source: Own source. Research data

To discuss how the knowledge and technology transfer process occurs at Labvir, the following section details its interaction with the spin-off Viriontech do Brasil.

6.2.1. Case 2 - Labvir - Viriontech : spin-off generation and patent transfer

Viriontech do Brasil is a biotechnology spin-off founded in 2004 by three Labvir professors who work in the areas of Virology and Disease Diagnosis. It works with biotechnology involving viruses, diagnosis, vaccines, and in improving other firms' products that are already in the market. Viriontech intended to act as a bridge of the laboratory results and products to the market and aimed at producing research inputs (HESPANHA, 2005, online).

The main events of this 15-year UII (2004-2019) are listed in Figure 14

Figure 14 - Chronology of the Labvir-Viriontech interaction.

2004 - Incorporation of Viriontech as a firm.
2005 - UFMG licenses 4 patents to Viriontech for EIA (Equine Infectious Anemia) diagnostic kits.
2005 - Viriontech was incubated by Biominas Foundation, a local biotechnology business incubator.
2005 - One of the spin-off's founders left Viriontech in December 2005.
2011 - UFMG and Viriontech suspend the licensing agreement of the 4 EIA patents.
2014 - UFMG licenses 1 of the EIA patent to the Bioclin firm.
2015 - Production of EIA diagnostic kits by Bioclin.
2017 - Bioclin was prevented from selling the EIA diagnostic kits because of legal issues.

Source: Own source. Research data.

In 2005, UFMG licensed four patents for EIA diagnostic kits to Viriontech. This technology was developed through research carried out in the laboratory since the early 1990s (E5). Until 2019, however, Viriontech had not directly produced this patented technology, despite being located at the specialized biotechnology incubator Biominas Foundation.

Nevertheless, this Labvir-Viriontech interaction allowed the laboratory to acquire experience in production processes in partnership with larger firms, as well as to disseminate the laboratory's technologies (E5). UFMG report on licensing agreements shows four patents of the EIA diagnostic kit licensed to Viriontech on March 15th, 2005, which contract expired in 2011. Hence, the technology transfer was undone after six years of interaction. Despite the transfer of four patents to Viriontech, this spin-off was unsuccessful in establishing a production line, due to the high costs to set up a production plant, strong competition, and extensive health regulations from ANVISA.

6.3. Discussions - Triple Helix relationships in the Brazilian cases

Based on the results presented, we discuss three main points: substitution of the triple helix (TH) functions, generation of spin-offs, and technology and knowledge transfer in the university-industry interaction.

6.3.1. Substitution between TH spheres

Some new functions were observed in the UII resulting from the helix spinning movement (Figure 15).

Figure 15 – New Triple Helix's functions in the helix spinning movement

	Original function	*New function*
Case 1 Labbio-Crômic interaction	UFMG: teaching and research activities in interaction.	University took up the role of the industry by disseminating the Crômic sneakers and partnering with campus shops to sell them.
Case 1 Labbio-Aptivalux interaction	Government agencies FINEP and FAPEMIG: the function of funding, regulating and controlling research and innovation, and developing innovation policies.	The Government took up the role of providing public venture capital to fund academic research with industrial interest.
Case 1 Labbio-Aptivalux interaction	Industry: generation of wealth and innovative products.	Spin-off took the role of the university in developing education and training, laboratory product dissemination, and purchasing equipment for the university research laboratory.
Case 1 Labbio-Aptivalux and Case 2 Labvir-Viriontech	UFMG: teaching and research activities in interaction.	University engaged in spin-off formation, providing support and sharing risks in calls for funding to encourage entrepreneurial ventures - traditional industry roles.

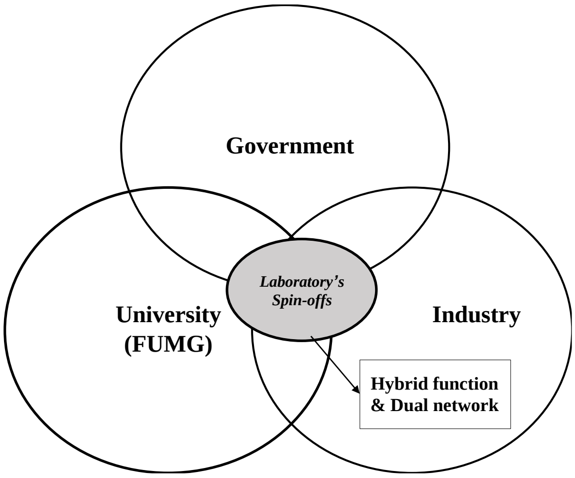
Source: Own source. Research data.

6.3.2. Spin-off generation – The path to an entrepreneurial university

Firm formation in knowledge-based societies involves three factors: human capital, material, and organizational factors (Etzkowitz, 2008). In the Brazilian case, all dimensions of human capital were observed: a critical mass of scientists, research with commercial potential, and scientists interested in starting a business. However, the material and organizational factors were not fully observed. There was a lack of equipment, research inputs, and available funding to set up a scale-up prototyping unit or production unit. It was observed an immature TTO to liaise laboratory and industry interactions to support finding and transferring technologies to the market. Additionally, the lab coordinators pointed out a lack of institutional support at UFMG for scientists to learn business skills, weak policies to encourage faculty and students to interact with industry, and insufficient biotechnology incubator facilities.

The emergence of academic spin-offs at UFMG plays a central role in an entrepreneurial university. However, the movement towards an entrepreneurial university is initial, considering that neither of the two spin-offs had, in 15 years, produced innovative products from the laboratory's patented technology. Instead, they acted as a consultant and broker firm with a "dual business intermediate hybrid function". This emergent hybrid function in the industry sphere, resulting from the university-industry interaction, expands the assumptions of the triple helix, which would have predicted a new hybrid institution (rather than a function) in this setting. This hybrid function involves marketing university research and brokering patent licensing. (Figure 16).

Figure 16 - Triple helix in Labbio and Labvir's spin-offs and the bilateral hybrid function



Source: Own source. Research data.

Some intellectual benefits from these two spin-offs include valuing university research, generating knowledge in management and entrepreneurship, and stimulating the applied research process. They generated economic benefits, such as sharing research costs with the laboratory and having relative independence in relation to funders' red tapes for resource use. There are also social benefits, such as fostering the culture of entrepreneurship at the university (Cozzi et al., 2008).

6.3.3. Technology and knowledge transfer in the university-industry interaction

In both laboratories, there was technology transfer (Rogers et al., 2001) through patent licensing and product sales, such as Crômic's sneakers, Chimiolux, and the EIA diagnostic kit. According to the lab coordinators, most of the interactions between the lab and firms or hospitals happened without patent transferring and did not involve the Technological Transfer and Innovation Coordination (CTIT), which role is to support the licensing process. Many reasons were raised to explain this, such as the multiple levels and time consumed in university instances for contract approval, and the lack of administrative support staff in the laboratories.

Informal channels of knowledge transfer, such as partnership with public hospitals for support in diseases diagnostic or printing facial masks, seem to be an important way to transfer knowledge and technology with social impact (Intarakumnerd and Schiller, 2009). Importantly, both laboratories presented long-term interactions with public hospitals, based on strong trust-based ties, what allowed students and researchers training with no formal contract or financial transaction involved (Hansen, 1992; Nooteboom, 1999).

The analysis of the UII channels made it possible to identify how the factors of infrastructure and people qualification influenced the knowledge transfer process. We observed that, in addition to the unidirectional and low-proximity channels, such as patent licensing and publications (Dutrenit and Arza, 2010), the results showed high-proximity channels (Perkmann and Walsh, 2007), such as research contracts for product development (Labbio-Crômic) and consulting services (Schiller and Lee, 2015). The key factors driving this diversity of interactions, in Labvir's case, for instance, are, first, the research team expertise in virology, according to the laboratory coordinator. Next, Labvir's interactions with many private and public hospitals for diseases diagnosis were driven by the laboratory's historical biological samples, and the availability of equipment, remarkably the infrastructure with Biosafety 1 and 2 levels.

This research identified a new institutional arrangement, led by laboratory spin-offs, which is characterized by high-proximity and bidirectional channels, such as cooperative R&D projects with large firms. Aptivalux and Viriontech liaise relationships between government agencies, such as FINEP, and other firms, such as Hypofarma, DMC, and Bioclin. These results corroborate the literature regarding the difficulty of small biotechnology firms to generate product innovation, in addition to the lack of financial resources to meet the requirements of regulatory agencies and perform in vitro and in vivo tests (Cassiolato et al., 2011).

7. Contributions, implications and future research

The main contribution of this article is providing empirical data on the role of university research laboratories as the locus of innovation within the university sphere in a developing country context. Despite research laboratories being the unit of analysis closest to the generation of knowledge and technology with the potential to become innovations, empirical studies on factors at the level of laboratories are yet a research gap in innovation and triple helix studies. Participants here are university professors, post-doc fellows and senior researchers who combine expertise in biotechnology academic research and spin-off firm creation experience. Results revealed a wealth of details about how laboratory's people and equipment, with the support of national and local incentives to UII, such as calls for sponsored university-industry research promoted the observed UIIs by fostering the entrepreneurial endeavors from the scientists and spin-off CEO's.

The process of knowledge and technology transfer observed in both laboratories presented the relevance of laboratory internal organization for the university community (students, researchers, professors, administrative staff) and society at large, mostly the local industry and national government ministries. These laboratories contribute to advance the biotechnology field in Brazil, through academic and technological results, such as patents, products, and professional training. The university UFMG presented an intermediary level of entrepreneurial university (Etzkowitz et al., 2008), facilitating industry interaction through their TTO – CTIT and the laboratories spin-off firms.

Our proposed analytical framework represents a contribution to analyze and interpret empirical data on the UII process for knowledge transfer considering the diversity of channels and potential results at the laboratory's level. By emphasizing human resources, equipment, and local UII incentives, this framework operationalized the relationships within the triple helix (Etzkowitz and Leydesdorff, 1995), and the set of factors that influence spin-offs' generation (human capital, material, and organizational factors) (Etzkowitz, 2008; Etzkowitz and Zhou, 2017). The generation of spin-offs is a traditional channel of UII in biotechnology (Cooke,2002), but our findings indicate that they face several challenges in a developing country, as discussed below. Moreover, the Triple Helix approach guided the understanding of each sphere's functions and interactive dynamics.

A relevant finding out of these interactions is that the two spin-offs face structural barriers to become autonomous industry actors and grow. This can be partly explained by they being in a developing country with an immature National Innovation System, in which low private investment in R&D prevail (Albuquerque, 1996; Albuquerque et al., 2015). However, these spin-offs developed creative ways to survive and generate revenues, such as one million reais in funding obtained by Aptivalux and the successful cases of technological consultancy service to other firms.

A novel contribution of this study is the identification of new institutional arrangements around spin-offs in the Brazilian context. The whole idea of a TH spiral and intersect spheres is the emergence of hybrid organizations, such as TTOs and business incubators (Etzkowitz, 2008).. However, our Brazilian data showed spin-offs as a formal incorporated firm with a hybrid function that is fundamental for their survival and to commercially exploit the laboratory technologies. They do not come into existence unless they perform this special hybrid function through university professors working as both spin-off founders and active members. These spin-offs contribute to the absorptive capacity of external firms and, above all, allow laboratories to disclose their results to potential end-users and buyers.

Implications

These findings offer new perspectives for universities and policymakers in Brazil and other developing countries in relation to the role of academic spin-offs in university-industry interactions for knowledge and technology transfer, at the local and national levels.

Network interactions between laboratory-university and spin-offs in biotechnology and health facilitate firm learning of new technologies and broaden absorptive capacity. This finding can support decision making by policymakers and industry stakeholders to develop policies for the generation of spin-offs as integral part of innovation laws and programs.

Future research

A relevant research agenda for further studies refers to expanding the scope of this research by testing the robustness of the proposed analytical framework to include the view of firms that interact with university research laboratories in biotechnology. Moreover, applying this framework to describe the process of spin-off formation and survival in other developing countries could expand the applicability of these findings.

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