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Research Article

Investigating the factors driving bidirectional relationships between universities and public research institutes, and Brazilian small and medium-sized enterprises

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Abstract

Objective: investigating the factors driving bidirectional relationships (i.e., "scientific research with considerations towards the immediate use of results" and "scientific research without considerations towards the immediate use of results") established between research groups (RGs) and Brazilian small and medium-sized enterprises (SMEs). **Methodology/approach:** estimating four logistic regression models to investigate the factors driving bidirectional relationships between RGs from the Brazilian Directory of Research Groups (DRG) of the National Council for Scientific and Technological Development and 1,819 companies with up to 499 employees. **Main results:** the economic sector and the access to public funding can influence the establishment of bidirectional relationships between RGs and SMEs. Some specificities of factors driving bidirectional relationships are identified in SMEs' different size ranges. **Theoretical/methodological contributions:** adopting a comprehensive database on collaborations between RGs and SMEs, based on information deriving from the Directory of Research Groups and from the Annual Report of Social Information, and approaching to a topic that remains poorly investigated in the literature. **Relevance/originality:** assessing how different driver categories influence the establishment of bidirectional relationships between RGs and SMEs and featuring the factors driving these relationships in interactive companies' different size ranges. **Social/Management Contributions:** Innovation policy should address the factors driving knowledge-related cooperation between public research organizations and SMEs.

Keywords: Small and medium-sized enterprises. Bidirectional relationships. Modes or channels of interaction. University-industry interaction.

Uma investigação sobre os fatores direcionadores (drivers) dos relacionamentos bidirecionais de universidades e institutos públicos de pesquisa e pequenas e médias empresas brasileiras

Resumo

Objetivo: investigar os fatores direcionadores (*drivers*) dos relacionamentos de tipo bidirecional (isto é, "pesquisa científica com considerações de uso imediato dos resultados" e "pesquisa científica sem considerações de uso imediato dos resultados") estabelecidos entre grupos de pesquisa (GPs) e pequenas e médias empresas (PMEs) brasileiras. **Metodologia/abordagem:** estimação de quatro modelos de regressão logística para investigar os fatores direcionadores dos relacionamentos de tipo bidirecional, estabelecidos entre GPs do Diretório dos Grupos de Pesquisa no Brasil (DGP) do Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) e 1819 empresas com até 499 empregados. **Principais resultados:** o setor de atividade e o acesso ao financiamento público são capazes de influenciar o estabelecimento de relacionamentos bidirecionais entre GPs e PMEs. Ademais, são identificadas especificidades dos *drivers* dos relacionamentos bidirecionais nas diferentes faixas de porte de PMEs. **Contribuições teóricas/ metodológicas:** exploração de uma base de dados abrangente sobre a colaboração entre GPs e PMEs, a partir da junção de informações do DGP e da Relação Anual de Informações Sociais (RAIS), e abordagem de uma temática ainda pouco explorada na literatura. **Relevância/originalidade:** avaliação de como diferentes categorias de fatores direcionadores conformam o estabelecimento de relacionamentos bidirecionais entre GPs e PMEs e caracterização dos *drivers* desses relacionamentos nas diferentes faixas de porte das empresas. **Contribuições sociais/para a gestão**: a política de inovação deve contemplar os fatores direcionadores da cooperação entre as organizações públicas de pesquisa e PMEs relacionada ao conhecimento.

Palavras-chave: Pequenas e médias empresas. Relacionamentos bidirecionais. Modos ou canais de interação. Interação universidade-empresa.

INTRODUCTION

Studies focused on investigating knowledge and technology transfer between public research organizations and companies addressed a wide spectrum of "channels" and "modes" of interaction, "relationships" and "links", as well as transfer "methods" and "mechanisms", which work as informational or social paths that are shared or co-produced, both in the academic environment and in the industrial sector, through different knowledge and technology types, among other resources (Fabiano et al., 2020).

The literature in this field has associated the use of different knowledge and technology transfer activities taking place in public-private interactions with getting results and benefits. Research contracts set by public research organizations and, mainly, joint research and development (R&D) projects make the exchange of non-codified information easier (Arundel & Geuna, 2004). Channels related to joint R&D and R&D contract, as well as to property rights and human resources, have the strongest impact on companies' long-term benefits (De Fuentes & Dutrenit, 2012). Interactions taking place through research and joint technological efforts can enable companies to access scientific knowledge and contribute to their innovative performance (Arza et al., 2015). Thus, they are positively correlated to the level of potential spillovers associated with participants' R&D expenditure (Branstetter & Sakakibara, 2002).

Bidirectional channels of interaction are intrinsic ways to transfer tacit knowledge. In addition, they often comprise long-term personal interactions through which knowledge flows in both directions (Arza, 2010; Arza et al., 2015; Franco & Haase, 2015; Suzigan et al., 2009). They cover research contracts and joint R&D projects, participation in networks, science and technology parks, and similar activities. Knowledge outputs, in bidirectional knowledge flows, must be created based on contributions from all actors. Bidirectional channels of knowledge have the potential to improve joint learning; thus, they can be the most effective way to transmit novelties and to enable technological upgrading. Bidirectional channels are encouraged by long-term goals of knowledge creation by universities and innovation by companies (Fabiano et al., 2020) and generate long-term innovative and productive benefits for companies, and intellectual benefits for researchers (Dutrenit, 2010; Arza & Vazquez, 2010; Garcia et al, 2019). They produce innovation benefits for all companies, which can interact with public organizations to either replace or add to their innovative activities (Arza & Vazquez, 2010).

The aim of the current study was to investigate the factors driving bidirectional relationships (i.e., "scientific research with considerations towards the immediate use of results" and "scientific research without considerations towards the immediate use of results") established between RGs belonging to the Engineering and Agricultural Sciences fields and Brazilian small and medium-sized enterprises (SMEs).

Bidirectional relationships between public research organizations and SMEs are of particular research interest, since these companies' innovative processes face several issues and obstacles associated with scarce internal resources (Molina-Ycaza & Sánchez-Riofrío, 2016; Zevallos, 2003). Establishing cooperative projects is an important way to overcome these obstacles to innovation (Arza & Lopes, 2021; Chiarini et al., 2020).

In order to explore the influence of different factors driving the establishment of bidirectional relationships between RGs and SMEs, the current study used a database created with data information from DRG, which was added with data from the Annual Report of Social Information (RAIS - Relação Anual de Informações Sociais) and with information from organizations supporting innovation in Brazil. Some structural and behavioral features of interactive companies and the S&T&I policy were herein addressed. The empirical analysis was based on four econometric models, which were estimated based on information about 1,819 SMEs that interacted with RGs from universities and public research institutes (PRIs) in the 2010 Census.

The present article was organized into six sections, in addition to this introduction. The second section presents the literature review on factors driving university-industry knowledge and technology transfer activities. The methodology presented in the third section describes the adopted database and the econometric models' estimation process. The fourth section presents the research results, which are analyzed in the fifth section, and the sixth section presents the final considerations.

FACTORS DRIVING KNOWLEDGE AND TECHNOLOGY TRANSFER ACTIVITIES BETWEEN PUBLIC RESEARCH ORGANIZATIONS AND COMPANIES

The literature focused on investigating the factors driving (drivers) channels or modes of university-industry interaction remains incipient. Some studies investigated the influence of companies' structural and behavioral factors, of geographic proximity between agents, as well as of stimuli arising from S&T&I policies, on companies' likelihood to interact with public research organizations through a given knowledge or technology transfer activity or through a set of them.

Studies (Arvanitis et al., 2008; Freitas et al., 2013; Torres et al, 2011) addressing the effects of internal resources' availability in small enterprises on the process to guide channels and modes of interaction and university-industry transfer activity remain scarce and there is no consensus regarding the influence of structural feature "company size". Arvanitis et al. (2008) observed positive relationship between company size and the likelihood of engaging in transfer activities associated with general information, in educational, research and technical infrastructure-related activities, and in consultancy. Larger enterprises presenting greater absorption capacity embodied in specialized R&D departments, knowledge and technology monitoring units and the use of advanced knowledge management methods are highly capable of identifying the best possibilities related to transfer activities. On the other hand, according to Torres et al. (2011), interactions with higher education institutions and public research centers, based on information and human resources' channels, presented negative association with company size. Large enterprises tend to establish their own R&D facilities, which provide them with information and human resource training to perform routine activities.

Small businesses often have few idle resources to set and organize contracts with universities (Freitas et al., 2013). The personal contract mode, which comprises binding and formal agreements between companies and individual scholars, without mediation by university administrative structures, is relatively more used by small enterprises involved in open innovation technologies and strategies. Institutional interactions are mainly used by large enterprises that vertically integrate R&D activities.

Studies in the literature have investigated whether channels and modes of interaction, as well as methods and mechanisms of transfer between the academic field and the industrial sector differ between companies' activity sectors and/or due to sectoral technological intensity, technological regime or technical field. Different studies observed that some channels are mostly used in public-private transfer processes and that the importance attributed to them can change across activity sectors. According to Cohen et al. (2002), open science channels - publications, public meetings and conferences -, informal information exchanges and consultancies are the most important ones. Enterprises presenting higher R&D intensity (food, petroleum, pharmaceutical, metals, semiconductors, aerospace, and medical equipment, among others) acknowledge consultancy activities' relevance (Cohen et al., 2002). Newly graduates play relatively important role in electronic components, communications equipment and computing

companies. Joint and cooperative ventures between universities and companies play, at least, moderately important role in the pharmaceutical, glass, steel, TV/radio, and aerospace sectors. According to Povoa and Rapini (2010), publications and reports are the main channel used by Brazilian economic activity sectors, except for the information and communication sectors, which use more informal conversations. Bekkers and Freitas (2008), in their turn, observed that sectoral activities do not significantly explain differences in the importance level attributed to several university-industry channels of interaction.

Some studies associated channels of interaction and transfer mechanisms with technical fields or science-based regimes that mostly perform basic research, as well as with development-based regimes focused on creating and transferring applied knowledge. The industrial sector's main interest in science-based fields, such as chemistry, information technology and biotechnology, lies on science observation - interactions are described through the bidirectional mode (Meyer-Krahmer & Schmoch, 1998). Collaborative research and informal contacts play important role in the microelectronics, software and biotechnology sectors. Solving technical issues is the main concern in lesser science-based fields. Contractual and collaborative research types stand out in production technology (machine tools and materials' processing). Knowledge exchange in technical-scientific communities is a crucial interaction factor in all fields.

Technology transfer in science-based regimes takes place through scientific publications, patents, academic spin-offs and consultancies (Gilsing et al., 2011). Joint R&D programs, participation in conferences and professional and/or regional networks, and the flow of PhD graduates are the most important means of knowledge transfer in development-based regimes. Both regimes present similar use of, and importance attribution to, personal and informal contacts, graduates' inflow, mutual staff exchange, facilities' sharing and contractual research.

With respect to technological intensity, Arundel and Geuna (2004) and Torres et al. (2011) observed that high-technology sectors prefer methods and channels that allow transferring tacit knowledge, such as informal personal contacts and hiring trained scientists and engineers. On the other hand, low-technology sectors prefer contractual research or joint research projects and codified sources of conferences/meetings and publications. According to Schartinger et al. (2002), technical sciences and R&D-intensive manufacturing companies tend to mostly use direct research cooperation, whereas services, and social and economic sciences, mostly rely on personnel mobility and training-related interactions.

According to Pinho (2011), joint research conducted with Brazilian academic institutions stands out in agriculture, medium-low technology companies, mining, public utility services and publications in engineering and R&D, as well as in public utility services and low and medium-high technology companies. Information and communication services, in their turn, prioritize personnel hiring and informal exchange of information. Britto and Oliveira (2011) observed that extractive and electricity companies attributed greater importance to research commissioned to universities, as well as that plastics and electricity companies attributed greater importance to research conducted by research institutes, centers and laboratories. Joint research is of paramount importance for the extractive, pharmaceutical and health biotechnology companies, in the case of universities, as well as for electricity and extractive companies, in the case of research institutes, centers and laboratories.

The literature also indicated that type of technology transferred (Povoa & Rapini, 2010), researchers' disciplinary origin or affiliation (Fabiano et al., 2020; Franco & Hasse, 2015) and characteristics of knowledge (Bekkers & Freitas, 2008; Fabiano et al., 2020; Franco & Haase, 2015) play important role in guiding channels of interaction.

With respect to companies' behavioral factors, some authors have evidenced that the emphasis placed on a given channel (or group of channels) can be determined by companies' motivation to interact with public research organizations. The motivation to interact responds to companies' need to: i) improve production capabilities - their role in creating knowledge is mostly passive; or ii) upgrade innovative capabilities - their role in creating knowledge is quite active (Arza et al., 2015). Companies often access knowledge products that are codified and ready to be used, such as testing and monitoring, in interactions aimed at solving real and short-term issues. Companies encouraged by proactive strategies are likely to cooperate through joint R&D (Arza, 2010; Arza et al., 2015).

Bekkers and Freitas (2008) observed two interaction patterns in companies aimed at becoming innovators or early adopters in their market, namely: i) focus on collaborative and contracted research to support the adoption of interdependent knowledge, mainly in biomedical and computer sciences; and ii) stronger dependence on patents, licensing and organized activities to support both the access to and adoption of systemic knowledge, mainly in Materials Sciences and Chemical Engineering. In both cases, companies count on scientific publications, as well as on informal contacts with researchers and students, to meet the need of engaging in scientific knowledge application to specific needs of their products and markets. Hall and Ziedis (2001), in their turn, highlighted studies suggesting that semiconductor companies do not strongly depend on patents to get appropriate R&D returns.

Different studies have advocated that innovative and technological efforts are linked to different channels of interaction. High human-capital intensity and internal R&D activities appear to be important prerequisites to help unfolding transfer activities, such as overall information; educational, research and technical infrastructure-related activities; and consultancy (Gilsing et al., 2011). Torres et al. (2011) have also stressed that training and personnel exchange turn into important PRIs' modes of interaction as companies develop R&D and innovative activities. R&D intensity shows positive correlation to interactions with higher education institutes associated with research products and services. Companies' innovative profile has negative effect on their channel establishment process. According to Arundel and Geuna (2004), graduates' recruitment, informal contacts and contractual research are the main methods for large enterprises performing R&D to access public science. Laursen and Salter (2004) suggested that several companies performing R&D do not commercially use university-related knowledge in their innovative activities, although they can indirectly do so through trained scientists and engineers.

Based on the literature, different interaction forms are linked to companies' absorption capacity. According to Freitas et al. (2013), companies engaging in institutional interactions mediated by university structure are more likely to invest in internal R&D and design. On the other hand, companies engaging in interactions ruled by contracts with individual researchers perform lesser internal R&D. Companies that mostly depend on technological acquisition from external organizations, through collaborations and intellectual property licensing, have likely developed search and "tracking" skills to identify knowledge providers, as well as technological coding ability to define and specify the content of knowledge/technology supply contracts.

Veugelers and Cassiman (2005) have emphasized that the effective transfer of knowledge outspread through publications, conferences and patents requires basic-research training by the receiving party. Accordingly, Arza and Vazquez (2010) have evidenced that only companies that strongly invest in innovation and production activities are capable of absorbing the highly codified knowledge type that does not require personal interaction inherent to the traditional channel (publications, graduates' training and participation in conferences).

A study conducted by Povoa and Rapini (2010) in Brazil has also indicated that partners' absorption ability increases the likelihood of using patents in technology transfer processes. According to Rosa et al. (2018), companies interacting with universities via consulting channel have greater assimilation skills, whereas companies interacting via joint research have greater acquisition and exploration skills. On the other hand, companies interacting via channels linked to entrepreneurial university do not present absorption skills different from those of other companies.

The influence of funding source on the definition of university-industry relationship patterns was also addressed in the literature. According to Freitas et al. (2013), basic research projects are likely sponsored, at least partly, by public funds, whose assignment often requires institutionalized collaboration forms. Jensen et al. (2010) have emphasized that the public funding of university research is positively correlated to consultancy. Public and private funding is a strategic complementation element in research funding processes. According to Muscio et al. (2013), public funding granted to university departments involved in research completes research financing and contracts' consulting. Moreover, it helps increasing universities' collaboration with the industrial sector and triggering knowledge transfer processes. On the other hand, Rapini et al. (2014) have pointed out that funding nature appears to interfere with Brazilian companies' goals or motivation to interact with universities, rather than with their modes of interaction.

Table 1 below synthesizes empirical articles focused on investigating the factors driving knowledge and technology transfer activities between public research organizations and companies.

METHODOLOGY

Data

Empirical analysis involves joint use of DRG and RAIS databases, as well as of information from agencies supporting innovation in Brazil. Primary data from interactions between university RGs/PRIs and companies refer to the 2010 census. The DRG database has been widely used in studies focused on investigating university-industry interactions in Brazil, since it is the inventory of active RGs and covers information about the structure and activities of RGs actively collaborating with companies (Caliari & Rapini, 2017).

A list of SMEs that interacted with RGs from the Engineering and Agrarian Sciences fields was extracted from the 2010 DRG census database, since these companies present the largest number of relationships with the productive sector (Suzigan et al., 2009; Righi & Rapini, 2011). The identified RAIS database was used to characterize the companies interacting with RGs. In order to do so, the National Register of Legal Entities (also known as CNPJ - Cadastro Nacional de Pessoa Jurídica) of both CNPq RGs' partner companies and RAIS were crosschecked. Information from companies benefiting from innovation-related public resources coming from institutions, such as the Funding Authority for Studies and Projects (FINEP - Financiadora de Estudos e Projetos), the Brazilian Development Bank (BNDES - Banco Nacional de Desenvolvimento Econômico e Social), the National Council for Scientific and Technological Development (CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico), the Ministry of Science, Technology and Innovation, and São Paulo Research Foundation (FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo), from 2005 to 2010, was added to this database.

Table 1

Synthesis of empirical articles about the factors driving knowledge and technology transfer activities between public research organizations and companies

Driving factor	Relationship between the driving factor and the importance attributed to, or use of, one or more transfer activities	Authors
1. Company's structural factors		
1.1 Size	Positive relationship	Arvanitis et al. (2008); Freitas et al. (2013)
	Negative relationship	Torres et al. (2011)
1.2. Activity sector	Positive relationship	Cohen et al. (2002); Povoa and Rapini (2010)
	Inexistent relationship	Bekkers and Freitas (2008)
1.3. Sectoral technological intensity	Positive relationship	Arundel and Geuna (2004); Torres et al. (2011); Schartinger et al. (2002); Pinho (2011); Britto and Oliveira (2011)
2. Company's behavioral factors		
2.1. Motivation to interact	Positive relationship	Arza (2010); Arza et al. (2015); Bekkers and Freitas (2008)
2.2. Innovative and technological efforts	Positive relationship	Arvanitis et al. (2008); Torres et al. (2011); Arundel and Geuna (2004); Laursen and Salter (2004)
2.3. Absorption capacity	Positive relationship	Freitas et al. (2013); Veugelers and Cassiman (2005); Arza and Vazquez (2010); Povoa and Rapini (2010); Rosa et al. (2018)
3. Factors arising from S&T&I policies		
3.1. Funding source	Positive relationship	Freitas et al. (2013); Jensen et al. (2010); Muscio et al. (2013)
	Inexistent relationship	Rapini et al. (2014)
4. Other factors		
4.1. Technical fields or technological regimes	Positive relationship	Meyer-Krahmer and Schmoch (1998); Gilsing et al. (2011)
4.2. Transferred technology type	Positive relationship	Povoa and Rapini (2010)
4.3. Researchers' disciplinary origin or affiliation	Positive relationship	Fabiano et al. (2020); Franco and Haase (2015)
4.4. Knowledge features	Positive relationship	Bekker and Freitas (2008); Fabiano et al. (2020); Franco and Haase (2015)

Note

The RGs' partner companies were featured based on the following variables: number of employees, number of employees with college education or higher schooling, economic activity sector, types of relationships with groups and access to public funding.

The SMEs were classified based on the employed personnel criterion, which is also used by institutions, such as Brazilian Micro and Small Business Support Service (SEBRAE - Serviço Brasileiro de Apoio às Micro e Pequenas Empresas) and Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística), namely: micro-enterprise (up to 19 employees); small business (from 20 to 99 employees); medium-sized company (from 100 to 499 employees); large company (more than 500 employees). The composition of the interactive SME sample included all companies with up to 499 employees in the DRG database. Data tabulation has indicated a set of 2,049 companies interacting with 1,330 RGs; it corresponded to 66.90% of RGs' partner companies in the 2010 Census.

Moreover, a filter was applied to the database in order to refine the company size criterion based on the number of employed individuals. It was done by using the so-called "CNPJ Raiz" (which comprises the first eight digits of the company registration number) to rule out large companies' branches. Companies presenting inconsistent information were also removed from the database. Thus, the analyzed data referred to 1,819 companies that had some relationship type with RGs (i.e., 59.3% of companies collaborating with RGs in the 2010 Census).

Econometric strategy

Information about "types of relationship" was herein extracted from DRG. This information was reclassified into two different types, namely: (1) bidirectional relationship, which happens in scientific research with considerations towards the immediate use of results and scientific research without considerations towards the immediate use of results; and (2) unidirectional relationship, which refers to technology transfer, software development, non-routine engineering, consultancy and training. This classification, which includes the direction of knowledge flows and relationships' intensity, was carried out based on the compatibilization of knowledge transfer channels - suggested by Arza (2010) and Arza and Vasquez (2010) - with types of relationships specified in the DRG database, carried out by Caliari and Rapini (2014) and Rapini et al. (2016). The aforementioned classification is justified by the differentiation of relationships involving bidirectional exchanges of information and knowledge between agents from companies that only adopt a univocal direction of service provision or technology and product development (Rapini et al., 2016).

The estimated models have bidirectional relationship as dependent variable, as reported by leaders of 2,317 CNPq RGs. Based on the 2010 DRG Census, the most frequent modes of interaction (67.69%) are bidirectional. "Non-classified" relationships were removed from the database .

The explanatory variables included the main factors identified in the literature as drivers of university-industry relationship types. The adopted explanatory variables can be classified into two categories related to: i) companies' structural and behavioral features (size, economic activity sector, and absorption capacity); and ii) the S&T&I policy (access to public funding).

The main hypothesis associated with the estimated models is that interactive companies' internal features, as well as factors related to the S&T&I policy, are factors driving bidirectional relationships between RGs and SMEs. Furthermore, given the heterogeneity featuring the small enterprises' segment (Arroio & Scerri, 2014; Nogueira, 2017), one can assume that drivers of SMEs' bidirectional university-industry relationships present specificities based on the investigated companies' size ranges.

SEBRAE and IBGE criteria set for SMEs belonging to the manufacturing sector were used in the case of companies' size. In other words, companies were categorized based on size ranges distributed as follows: a) up to 19 employees; b) from 20 to 99 employees; and c) from 100 to 499 employees. According to previous studies, companies' size is expected to have positive effect on the likelihood of establishing bidirectional university-industry relationships.

Seven dummies were inserted in the model to control technological opportunities between economic activity sectors and to represent inter-industry differences in interaction patterns, namely: 1) science-based and R&D-intensive industrial sectors; 2) agriculture, livestock, forestry and logging, fishing, aquaculture and related services; 3) trade and other services; 4) supplier-dominated industrial sectors; 5) specialized supplier industrial sectors; 6) knowledge intensive business sectors (KIBS); and 7) others . "Science-based and R&D-intensive industrial sectors" was the category treated as reference. Sectoral technological intensity is expected to have positive effect on the likelihood of bidirectional relationships to happen.

Company's absorptive capacity, which is measured through the number of employees with college education or higher schooling in comparison to the total number of employees, was another variable included in the empirical model. The availability of personnel with college education or higher schooling is expected to influence the establishment of bidirectional relationships between RGs and SMEs. Finally, a dummy that takes into consideration whether the company had access to public funding, or not, was added to the model. Companies benefiting from some public funding mechanism for innovation activities are expected to further engage in bidirectional relationships with RGs. The definition of the adopted variables is shown in Table 2.

Table 2

Description and source of variables and proxies

Variable	Description	Source
RelBidired	Bidirectional relationships between companies and research groups	DRG/CNPq Census 2010
NoEmp	Number of employees in the company	RAIS, 2008
SAT	Dummies for the economic activity sector Proxy for technological opportunities	RAIS, 2008
AbsorCF	Rate of employees with college education or higher schooling in the company Company's absorptive capacity proxy	RAIS, 2008
FinPub	Dummy for public funding	BNDES, FINEP, CNPq, MCTI FAPESP

Note: Elaborated by the authors.

The selection of a given logistic regression model depends on the possibility to analyze the likelihood of the bidirectional university-industry relationship to happen. Since the dependent variable "type of relationship" is dichotomous, the incidence of bidirectional university-industry relationship was defined as success.

The logistic regression model was estimated by maximizing a log likelihood function in order to get the estimated parameters most likely to have generated the observed sample of RelBirired_i values so that the likelihood of observing "y" values is as high as possible.

A logistic regression model was estimated based on the variables described below in order to estimate the likelihood of a bidirectional university-industry relationship to happen:

$$RelBidired_{i=}\begin{cases}1\ if\ the\ relationship\ was\ bidirectional\\0\ \ if\ otherwise\end{cases}$$

$$P\ (RelBidired_i\ =1)=\ \theta_i\ ,0\leq\ \theta\leq 1$$

$$log\left(\frac{\theta_i}{1-\theta_i}\right)=\beta_0\ +\beta_1\text{NoEmp}_i+\beta_2\ SAT(Setor2)_i\\+\ \beta_3\ SAT(Setor\ 3)_i+\ \beta_4\ SAT\ (Setor4)_i\\+\ \beta_5\ SAT(Setor\ 5)_i+\ \beta_6\ SAT(Setor6)_i\\+\ \beta_7 SAT\ (Setor7)_i+\ \beta_8\text{AbsorCF}_i\\+\ \beta_9\text{FinPub}_i\ ,i=1,\dots$$

Logistic regression models were estimated based on using the R tool. Four logistic regression models were estimated to investigate the factors driving bidirectional relationships between RGs and SMEs. Firstly, a model that took into consideration all DRG's interactive companies with up to 499 employees was estimated. Then, three models were adjusted and these very same companies were categorized by size ranges, based on employed personnel, according to previously described criteria.

RESULTS

Econometric estimation results - general model

Results observed for the model referring to companies with up to 499 employees have shown that factors (1) activity sector and (2) access to public funding can influence the establishment of bidirectional relationships between RGs and Brazilian SMEs (Table 1). SAT variables referring to sector "trade and other services", supplier-dominated industrial sectors; specialized supplier industrial sectors; KIBS, among others, recorded negative and statistically significant coefficients, and it implied reduced likelihood of bidirectional university-industry relationships to happen in companies belonging to each of these sectors in comparison to the reference category (science-based and R&D-intensive industrial sectors).

The positive sign of the coefficient observed for variable "public funding" implies increased likelihood of bidirectional relationships to happen with SMEs that accessed public funding in comparison to those that did not access it. Therefore, the hypotheses underlying the relationship between the activity sector and the availability of financial resources, and the establishment of SMEs' bidirectional university-industry relationships were confirmed.

If one assumes that the other variables are fixed, it is possible estimating that the likelihood of a given RG to have bidirectional relationships with companies belonging to the "trade and other services" sectors corresponds to 44.78% of the likelihood of companies belonging to the science-based and R&D-intensive industrial sectors to do so. The likelihood of a given RG to establish bidirectional relationships with companies belonging to supplier-dominated industrial sectors corresponds to 58.00% of the likelihood of those belonging to the aforementioned reference category to do so. In addition, the likelihood of bidirectional relationships with companies belonging to KIBS to happen corresponds to 58.36% of the likelihood of companies belonging to science-based and R&D-intensive industrial sectors to do so.

On the other hand, the likelihood of a given group to have bidirectional relationships with companies receiving public funding is 27.21% higher than that of companies that did not have access to such funding to do so.

In addition, no evidence capable of identifying the role played by structural feature "company size" and by behavioral feature "absorptive capacity" in guiding SMEs' bidirectional relationships was found in the current study (Table 3).

Econometric estimation results - models based on company size

Results of the models based on range of employed personnel to control the effect of variable "company size" have shown that belonging to sectors, such as agriculture, livestock, forestry and logging; fishing, aquaculture and related services; trade and other services; as well as having access to public funding, influences the likelihood of companies with up to 19 employees to establish bidirectional university-industry relationships (Table 2).

With respect to the intermediate size range (from 20 to 99 employees), belonging to sectors, such as trade and other services, supplier-dominated industrial sectors, and specialized supplier industrial sectors, can influence companies' involvement in two-way relationships with RGs. As for companies in the range from 100 to 499 employees, assumingly, none of the investigated variables is capable of influencing the establishment of bidirectional university-industry relationships. Furthermore, one cannot conclude that "number of employees" and "absorptive capacity" can influence the likelihood of bidirectional university-industry relationships to happen in these three company size ranges.

Table 3

Result of adjustments applied to the logistic regression model for companies with up to 499 employees

Term	Coefficient	Standard error	t-statistics	p-value	Exp (Coefficient)	Lower limit (2.5%)	Upper limit (97.5%)
Constant	0.9601	0.1491	6.4382	<0.001 ***	2.6119	1.9499	3.4985
NoEmp	0.0007	0.0004	1.6820	0.0927 *	1.0007	0.9999	1.0014
SAT (Sector 2)	-0.1832	0.2305	-0.7949	0.4268	0.8326	0.5300	1.3080
SAT (Sector 3)	-0.8033	0.1583	-5.0761	<0.001 ***	0.4478	0.3284	0.6107
SAT (Sector 4)	-0.5446	0.1693	-3.2170	0.0013 ***	0.5800	0.4162	0.8083
SAT (Sector 5)	-0.6828	0.1977	-3.4530	<0.001 ***	0.5052	0.3429	0.7444
SAT (Sector 6)	-0.5386	0.1784	-3.0187	0.0026 ***	0.5836	0.4114	0.8279
SAT (Sector 7)	-0.5499	0.2080	-2.6438	0.0083 ***	0.5770	0.3838	0.8674
AbsorCF	0.0002	0.0016	0.1108	0.9118	1.0002	0.9970	1.0033
FinPub (Sim)	0.2407	0.1185	2.0303	0.0424 **	1.2721	1.0084	1.6048

Note: Elaborated by the authors, based on DRG and RAIS. Number of research groups = 2,317; Pseudo R^2 by Cox & Snell = 0.0205; *Significant at 10% level (0.1); ** Significant at 5% level (0.05); ***Significant at 1% level (0.01)

The current study also provides evidence of the influence exerted by the "trade and other services" sectors on companies belonging to size ranges "up to 19 employees" and "intermediate" (from 20 to 99 employees), and it implies reduced likelihood of these companies to have bidirectional relationships in comparison to those belonging to the science-based and R&D-intensive industrial sectors. Belonging to sectors, such as agriculture, livestock, forestry and logging; fishing, aquaculture and related services; among others, implies reduced likelihood of companies in the smallest investigated size range to establish bidirectional relationships in comparison to those belonging to the reference category. Moreover, belonging to supplier-dominated industrial sectors and to specialized supplier industrial sectors leads to reduced likelihood of companies comprising from 20 to 99 employees to establish bidirectional university-industry relationships.

Public funding is only a driver of bidirectional relationships in companies with up to 19 employees. The likelihood of a given RG to have bidirectional relationships with companies presenting this size range and that have received public funding is 58.15% higher than that of companies that did not have access to it (Table 4).

RESULTS DISCUSSION

Results observed for the general model highlighted the activity sector and public funding, which are associated with bidirectional relationships with RGs. Models based on company size pointed out the specificities of factors driving bidirectional relationships at different SME ranges, and it indicated the high structural heterogeneity associated with Brazilian companies' size.

Results referring to the activity sector corroborate previous studies that associated bidirectional channels of interaction with science-based fields or regimes and with sectoral technological intensity (Meyer-Krahmer & Schmoch 1998; Schartinger et al., 2002; Britto & Oliveira, 2011). Based on the general model, the likelihood of a given RG to have a bidirectional relationship with SMEs in trade and other services' sectors, supplier-dominated industrial sectors, specialized supplier industrial sectors, KIBS, among others, is lower than that of companies belonging to science-based and R&D-intensive industrial sectors. The exception applies to sectors like agriculture, livestock, forestry and logging, as well as to fishing, aquaculture and related services, which are only capable of influencing the establishment of bidirectional relationships in companies with up to 19 employees . The concentration of these interactions in a limited number of companies and in sectors with less technological content was previously pointed out by Britto and Oliveira (2011) and Pinho (2011). With respect to models based on company size, the analyzed size ranges have evidenced differences in activity sectors' influence in reducing the likelihood of establishing bidirectional university-industry relationships in comparison to the reference category.

Although only 16.22% of companies had access to some public funding tool, this variable is an important driver of bidirectional relationships set by SMEs, mainly by those with up to 19 employees. These companies seem to depend on public support to establish relationships, according to which, companies and RGs interact and exchange information and knowledge (Suzigan et al., 2009). It is reasonable assuming that companies in the intermediate and higher size ranges experience relatively higher availability of internal resources to fund their joint research projects with RGs.

Variable "number of employees" is not a driving factor for bidirectional university-industry relationships. There is evidence that features intrinsic to each size range (in separate or combined to other investigated factors) can influence the establishment of these relationships, when the size effect of SMEs is controlled. Features intrinsic to size range "100 to 499 employees" may be factors driving bidirectional relationships. These companies present relatively high likelihood to establish these relationships; however, this behavior only depends on their inclusion in this specific size range.

The result recorded for variable "absorptive capacity" in all four estimated models was unexpected and contradicted previous studies (Arza & Vazquez, 2010; Freitas et al., 2013; Povoa & Rapini, 2010; Rosa et al., 2018; Veugelers & Cassiman, 2005). Firstly, one can assume that this result is associated with scarcity of human

Table 4

Coefficient estimates – logistic regression models based on interactive SMEs' size ranges

Terms	Estimates based on size ranges								
	(0.19]			(19.99]			(99.499]		
	Coef. (Standard error)	Exp (Coef.)	95% CI	Coef. (Standard error)	Exp (Coef.)	95% CI	Coef. (Standard error)	Exp (Coef.)	95% CI
Constant	1.2072(0.2860)***	3.3442	[1.9091; 5.8578]	1.1716(0.2440)***	3.2273	[2.0005; 5.2064]	0.7247(0.0796)***	2.064	[1.766; 2.413]
SAT (Sector 2)	-0.9072(0.3866)**	0.4037	[0.1892; 0.8611]	-0.1012(0.4141)	0.9038	[0.4014; 2.0347]			
SAT (Sector 3)	-1.2273(0.3034)***	0.2931	[0.1617; 0.5312]	-0.8783(0.2817)***	0.4155	[0.2392; 0.7217]			
SAT (Sector 4)	-0.6616(0.3408)*	0.5160	[0.2646; 1.0063]	-0.8840(0.2914)***	0.4131	[0.2334; 0.7313]			
SAT (Sector 5)	-0.7609(0.3937)*	0.4672	[0.2160; 1.0108]	-0.8532(0.3369)**	0.4261	[0.2201; 0.8246]			
SAT (Sector 6)	-0.6281(0.3275)*	0.5336	[0.2808; 1.0138]	-0.6484(0.3306)*	0.5229	[0.2735; 0.9996]			
SAT (Sector 7)	-1.3094(0.3913)***	0.2700	[0.1254; 0.5813]	-0.3832(0.3956)	0.6817	[0.3139; 1.4802]			
FinPub	0.4584(0.2072)**	1.5815	[1.0537; 2.3737]						
Pseudo R^2 by Cox & Snell	0.0389			0.0234			1.406710^{-13}		
N. obs.	883			717			717		

Note: Elaborated by the authors, based on DRG and RAIS. N. of observations; *Significant at 10% level (0.1); ** Significant at 5% level (0.05); ***Significant at 1% level (0.01)

resources with college education or higher schooling in a significant number of SMEs. These individuals play key role in exchanging information and knowledge with public research organizations, and they likely behave as knowledge "gatekeepers" in cooperative relationships (Oliveira et al., 2018).

Secondly, although SME interactions mostly encompass short- or long-term scientific research, it is likely that a significant number of these companies' demands to universities and PRIs do not require complex skills and are not close to the limits of scientific knowledge. This argument is corroborated by a specific feature in the pattern of cooperative relationships between Brazilian SMEs and RGs: almost half of bidirectional relationships are established with companies in the trade and other services' sectors, except for KIBS (26.90%) and supplier-dominated industrial sectors (22.40%). This finding is in line with that reported by Caliari and Rapini (2017), who identified a paradoxical dynamics in Brazil, namely: although the analyzed interactions were mostly bidirectional relationships, most of them were carried out with companies linked to trade and services' provision, which did not represent the main locus of the industrial innovative environment. Results observed in the current study were associated with the specialization of the national productive structure and with the prevalently incremental nature of the generated innovations (Bastos & Britto, 2017).

CONCLUSION

The current study has contributed to the topic "knowledge and technology transfer between public research organizations and SMEs" in the following ways: (1) by exploring a comprehensive database about this interaction by combining information deriving from DRG and RAIS; (2) by assessing how different categories of driving factors shape the establishment of bidirectional relationships; and (3) by featuring the factors driving relationships in different company size ranges.

Results regarding the activity sector's driver must be interpreted by taking into consideration features of the Brazilian productive structure. Results observed for models focused on controlling the effect of "company size" have suggested that the number of factors influencing the establishment of bidirectional relationships with RGs appears to decrease as the number of SMEs increases. The effect of size on the upper size range is noticeable. Thus, this issue should be further explored in future studies.

The current findings can be translated into policy recommendations. It is essential encouraging policies focused on promoting interactions between public research organizations and companies to take into account the factors driving knowledge-related collaborations. Promoting research, with (and without) taking into consideration the immediate use of results involving SMEs, seems to be a quite opportune strategy, since bidirectional relationships are capable of generating long-term benefits to help improving companies' innovative skills.

Results in the current study further reinforce the relevance of public funding to help establishing bidirectional relationships. Access to credit and innovation funding mechanisms seems very opportune, since it promotes the development of SMEs' absorptive capacity and favors the increased exploitation of external knowledge through bidirectional channels. It is interesting inducing research partnerships involving higher complexity, risk and cost, which would hardly be funded with their own resources (Oliveira et al., 2018). There is also broad space for innovation policies aimed at strengthening short- or long-term cooperative research, based on specificities of company size ranges. It is quite appropriate focusing on promoting innovative activities of companies with up to 19 employees, which have lesser access to public funding and use lesser diversified funding sources.

It is important pointing out some limitations of the present study, which are mainly associated with the adopted methodological approach. The first limitation refers to the sampling process featured by the scope of collaborations between companies and RGs belonging to the Engineering and Agricultural Sciences fields. Further studies should be conducted to include interactions with other knowledge fields. The second limitation lied on the fact that using the indicator "relationship type", deriving from DRG, which is the only public source available in Brazil, resulted in the modeling of a phenomenon whose analysis unit lies on relationship level and whose dependent variable-categorization process was based on group leaders' perspective. Suzigan et al. (2009) and Righi and Rapini (2011) have previously pointed out limitations and problems inherent to the process of collecting data from this Directory, since they derive from the self-declaration and subjectivity of leaders' individual perceptions. It is interesting gathering information about companies collaborating with RGs to further analyze their viewpoint.

The future research agenda highlights the importance of incorporating the temporal perspective in the process of modeling the investigated phenomena. The temporal approach can be used to capture the effects of factors driving bidirectional relationships between RGs and SMEs over time, and it enables assessing how the relationship between universities and SMEs affects the accumulation of new skills in these companies, with positive effects on interactive learning processes and innovation.

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Conflict of interest statement

The authors declare that there is no conflict of interest.

Authors' statement of individual contributions

Roles	Contributions	
	Oliveira, V. C. P.	Garcia, R.
Conceptualization	■	■
Methodology	■	■
Software	■	
Validation	■	■
Formal analysis	■	■
Investigation	■	■
Resources	■	■
Data Curation	■	■
Writing - Original Draf	■	
Writing - Review & Editing	■	■
Visualization	■	■
Supervision		■
Project administration	■	■
Funding acquisition	■	

Note: Acc. CRediT (Contributor Roles Taxonomy): https://credit.niso.org/

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