RN Revista de Negócios
Studies on emerging countries

Analysis of the Relationship between Research Groups and Firms

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KEYWORDS

Research Groups, CNPq, Triple Helix, Firms Relationship, Innovation.

Received 31.07.2020
Reviewed 14.04.2021
Accepted 27.04.2021

ISSN 1980-4431
Double blind review

ABSTRACT

This research focuses on the interaction between universities and firms, considering a society based on the knowledge economy. The aim is to identify relationships between research groups and firms that most contribute to the innovative performance of Brazilian Public Educational Institutes (PEIs). The adopted database was the tabular plan of 2010, from the Research Groups Directory of CNPq. The method was based on statistical techniques, such as Spearman Correlation, Cluster Analysis, ANOVA and Discriminant Analysis. As a result, the most relevant relationships obtained were the transfer of technology developed by the group to the partner; non-routine engineering activity, including development/manufacturing of equipment for the group; and scientific research with considerations of immediate use, respectively. It is therefore emphasized that the encouragement of certain relationships can support an increase in the innovative potential of PEIs. As practical contributions, it is argued that these results help PEIs on determining innovative paths, which are based on development and transfer of technology, as well as the realization of practice-oriented research.

PALAVRAS-CHAVE

Grupos de pesquisa, CNPq, Tríplice hélice, Relacionamento com empresas, Inovação.

RESUMO

Este trabalho foca na interação entre universidades e empresas considerando a sociedade baseada na economia do conhecimento. Com o objetivo de identificar os relacionamentos entre grupos de pesquisa e empresas que mais contribuem para o desempenho inovador das Instituições Públicas de Ensino (IPEs) brasileiras, utilizou-se como base de dados o plano tabular do ano de 2010, do Diretório dos Grupos de Pesquisa do CNPq. A metodologia foi baseada em técnicas estatísticas, como Correlação de Spearman, Análise de Cluster, ANOVA e Análise Discriminante. Como resultado, obteve-se como como os relacionamentos mais importantes a transferência de tecnologia desenvolvida pelo grupo para o parceiro; desenvolvimento de software não-rotineiro para o grupo pelo parceiro; atividade de engenharia não-rotineira inclusive desenvolvimento/fabricação de equipamentos para o grupo; e pesquisa científica com considerações de uso imediato, respectivamente.Assim, enfatiza-se que o estímulo a determinados relacionamentos pode suportar um aumento do potencial inovador das IPES. Como contribuições práticas, argumenta-se que esses resultados auxiliam as IPES na determinação de caminhos inovadores, sendo estes baseados em desenvolvimento e transferência de tecnologia, assim como na realização de pesquisa orientadas para a prática.

1 Introduction

Globalized economic development has, over the time, reinforced the role of knowledge as a fundamental input of the innovative process, becoming, along with learning, the main sources of competitiveness. In this context the relevance of universities emerges as the main locus where knowledge and innovation are created (Rapini, Oliveira e Silva, 2016; Brekke, 2021). The national environment that seeks a better competitive positioning in global terms needs to develop its ability to create knowledge. Brazil fits this reality, even though still deficient regarding qualified labor, it has meaningful academic and scientific communities. In addition to this fact, the knowledge infrastructure is not well used by the private sector as it has the potential to be (Rapini & Righi, 2006; Souza, Zambalde, Mesquita, Souza, Silva, 2020). These considerations are brought to support the affirmation that the increase of university-firm interactions leads to innovative advances, directing the national context to the best posture in the face of global competitiveness (Rapini & Righi, 2007). The interaction between universities and firms (U-F) leads to a bilateral process of technology and knowledge transmission. (Meyer-Kramer & Schmoch, 1998), articulating scientific and technological infrastructure to institutionalism (Pavitt, 1998). This interaction brings up concepts like National Innovation System (NIS) and Triple Helix (3H). This work focuses on Triple Helix, since it exposes the importance of higher education to innovation, basing itself on the knowledge economy (Carayannis, Campbell & Rehman, 2016). Therefore, Triple Helix also enables the needed support to the findings of this study.

The concept of Triple Helix was stated by Henry Etzkovitz around 1990. In this model, the government-university-industry relationship is considered fundamental to the creation of a sustainable innovation system. This ends up stimulating the “emergence of incubator cores, innovation cores, technology transfer offices, new laws, funding mechanisms" (Valente, 2010, p. 6), technology parks, research institutes (Etzowitz, 2009) and research groups, this being the focus of this work.

The analysis of research groups is justified by considering them as basic units of the university. They promote and manage activities based on knowledge and innovation, as the engine of science and technology (Wang & Hicks, 2015; Qian, 2016; Aguiar-Díaz et al., 2016; Kyvik & Reymert, 2017). By using research groups as a base to operate the U-F interaction, previous studies that address the theme of relationship from different perspectives were followed. As examples, the studies of Rapini and Righi (2006), Rapini and Righi (2007), Rapini, Oliveira and Silva (2016), Souza, Antunes, Azevedo, Angélico and Zambalde (2019) and Garcia, Araújo, Mascarini, Santos and Costa (2019) are indicated.

The authors mentioned above highlight that there are demands for better understanding'' U-F relationships. These demands aim to support and foster strategic actions that can affect the potential benefits that expand beyond the related helices. Based on this gap, it is sought to answer the following problem: which relationships, between research groups and firms, contribute the most to the innovative performance of Brazilian Public Educational Institutes? Highlighting that, by understanding the universities' innovative performance, it could emphasize the impact of these institutes on the productive sector. Therefore, this article’s aim is to identify the relationships that contribute the most to the innovative performance of Brazilian Public Educational Institutes (PEIs). To this end, data from the Research Groups Directory of the National Council for Scientific and Technological Development (CNPq) was used.

Consequently, this work involves the available data from the Research Groups Directory of the CNPq from the 2010 Census, with focus on relationships between research groups and the productive sector. The collected data refer to 2010 (the last year of availability of the tabular plan).

The development of this study is justified and motivated by the following authors: Rapini and Righi (2006, 2007), Souza et al. (2019) and Brekke (2021). Accordingly, Rapini and Righi (2006) claim that current studies of U-F interaction are empirical and reveal little about Brazil's scenery. The study therefore uses a national database, which allows us to present the general context of innovation produced by universities in Brazilian territory. For Souza et al. (2019) the analysis of U-F relationships should not be based only on these relationships' quantitative aspects, but on the contributions that these interactions can generate and disseminate to innovation. In this aspect, the investigation has the potential to identify, qualitatively, relationships that have the ability to manage and disseminate innovation. Lastly, Brekke (2021) highlights that, considering the role and process of authors, there is a need for studies that explore relationships as development engines. Therefore, this study's result has the ability to point to the role and process of university as a development promoter.

Finally, this article's results contribute theoretically to a detailed comprehension on operating two spheres of the Triple Helix. The results also support future analyses of this theory, providing data for more robust discussions about the universities' role and impact on society. In social terms, the results of U-F interactions have the potential to support the development of solutions for environmental and social issues. Moreover, in the practical scope, the findings provide guidelines to determine innovative and legal options. The rest of the study is divided in five sections: theoretical background, method, analysis of results and discussion, conclusion and implications and future research

2 Theoretical Background

2.1 The university-firm interaction by the triple helix perspective focusing on innovation

The interaction between firms and universities has an important role in the ability to combine and absorb knowledge (Rapini & Righi, 2007) and generate innovation. The combination of education and research in universities emerged in the early XIX century. Historically, the institution transitioned from a higher education institute to an institution with social purpose in education and research. Hence, universities became environments to integrate and differentiate the functions of knowledge base, in other words, they provide integration between academic education, theory and practice. (Etzkowitz & Leyersdorff, 1995, Souza et al., 2020).

The interaction between universities, the productive sector and government is particular to each country and exists in a competitive context where innovation is crucial. Thus, the creation of technology and knowledge transfer mechanisms add differentials in reaching and maintaining these institutions on the globalized system (Meyer-Kramer & Schmoch, 1998). In this context, the Triple Helix concept arises. According to Etzkowitz, Webster, Gebhardt and Terra (2000), the concept was suggested as a new institutional setting arisen from innovation systems that presents agents in network. The focus on the interaction between university, industry and government highlights the creation of hybrid arrangements where innovation is central and boosted by university, and, besides this, the government does not have the main role (Etzkowitz, Mello & Almeida, 2005).

The communication between the actors has a spiral pattern, where links emerge in various stages of the innovation process. The institutional and national boundaries go beyond, creating innovation environments as academic research groups, laboratories, incubators, among others (Etzkowitz & Leyersdorff, 1995, Brekke, 2021). These institutional boundaries, when exposed to dynamic relationship and interaction, bring a “first step to create the necessary and sufficient conditions to the sustainable innovation and development in a national or regional system” (Park & Leydesdorff, 2010, p. 641).

The participants of a Triple Helix have determinant features and roles. The universities act as the development engine based on knowledge of science and technology. The government is the keeper of interactions stability, supplier of incentive, benefits and research funding, legal activities. The firm, in contrast, represents the production of goods and services. It is also related to knowledge by encouraging and promoting it, both by training people and new ventures, guiding itself to research and market (Etzkowitz, 2009; Laguna, & Durán-Romero, 2017). Hence, the Triple Helix can be defined as a model in which its participants are related in a dynamic process of knowledge paths (Brekke, 2021). In this study, the interaction between firm, university and research institutions is focused through research groups. This interaction is then defined as a mechanism to fund the obtaining/supply of inputs to generate and develop innovation. The government, in this perspective, stands as the environment-influencing agent, where these interactions take place, as previously said.

2.2 Research groups: the university emphasis

In the current society, science is becoming the main development axis, here being represented by universities. These have a fundamental role on scientific knowledge performing in different ways, as specialized people training (Rosemberg & Nelson, 1994), development of basic or applied scientific research (Nelson, 1990; Rosemberg, 1992), spin-offs (Etzkowitz & Leyersdorff, 2000), technology and academic entrepreneurship transfer (Haase, Araújo & Dias, 2005). Thus, university is the economical and innovation engine for progress (Aguiar-Díaz, Díaz-Díaz, Ballesteros-Rodríguez & Sáa-Pérez, 2016).

Research groups are placed in this context. Considered as basic units of university and seen as social entities, the research groups are composed by members with interdependent tasks based on complementary abilities (Guzzo & Dickson, 1996). They focus on the common goal to develop research, science and technology (Wang & Hicks, 2015; Qian, 2016) sharing material and financial resources (Aguiar-Díaz et al., 2016).

According to Kyvic and Reymert (2017), the adherence to research groups increases productivity and quality of publications. In this way, research groups are friendly environments to obtain and share intellectual abilities, as well as to obtain access to research funds. Research groups allow for the network expansion at national and international levels, acquiring knowledge on planning, development and research methods. The groups are shown as complementary sources of knowledge acquired in courses from the curriculum framework (Haan, Leeuw & Remery, 1994; Odelius, Abbad, Junior, Sena, Viana & Freitas, 2011; Kyvik & Reymert, 2017), helping the researcher development, in terms of methodological and intellectual expertise (Feldman, Divoll & Rogan-Klyve; 2013). Feldman et al. (2013) suggests that the participation in these groups promote relationships in which mentorship does not come just from the professor, whose participation and disposition is still fundamental. Thus, by working in a coordinated way based on cooperation, besides technical and theoretical abilities, the researcher acquires and/or develops social abilities (Odelius et al., 2011).

In Brazil, CNPq, through Research Groups Directory (RGD), categorizes and makes data available on research groups with the aim to promote the exchange of information. The RGD works as an instrument to plan and manage activities of science and technology, developing and preserving the memory of scientific-technological activity in the country. Studies such as that from Rapini e Righi (2006, 2007), which uses the RGD database, points out that research groups also contribute to the relationships with the firms. According to the results of the authors, in 2002 and 2004, 74% and 92%, respectively, of the amount of relationships originated from the group to the firm. Among the relationship types, in this period, the non-routine engineering activities, technical consulting, scientific research both with and without considerations of immediate use of the results and technology transfer were highlighted as the most performed between the agents. The authors emphasize that the "supremacy of the scientific research of immediate use and technology transfer is closer to the university, including the advance of the development of a common language" (Rapini & Righi, 2007 p.259). However, "a significant part of the relationships is an unidirectional flow from the university and institutions to the firms”. (Rapini & Righi, 2006 p. 20). Rapini and Righi (2006) highlight that, even though narrowing and refining collaborative processes between firms and universities, research groups are still restricted to some firms, which presents an opportunity to increase interactions.

2.3 Innovative performance in public educational institutions

The innovation, originated from allocation and use of resources, behavior and activity, should be understood as a contextualized process, which is submitted to factors and dynamics. To generate and manage innovation requires strategy and policies that support the ability to innovate (Quandt, Bezerra & Ferraresi, 2015). Organizational innovation efforts, determinants of innovative performance, are targeted to improve products, process and organizational structure (Gunday, Ulusoy, Kilic & Alpkan, 2011; Quandt, Bezerra & Ferraresi, 2015). Hence, the innovative performance is related to strategy, leadership, culture, organizational structure, process, people, relationship, technological infrastructure, measurement and learning, factors that provide conditions and enable innovation. Among these aspects, the importance of relationships with external agents is highlighted (Quandt, Bezerra & Ferraresi, 2015).

The inherent difficulty to innovative activity refers to the need to identify and measure the determinants. As innovative activities' parameters there are: research and development (R&D), patents, new products, technology and other factors, related to determination of an innovative performance (Hagedoorn & Cloodt, 2003; Fernandes, Lourenço & Silva, 2014; Quandt, Bezerra & Ferraresi, 2015). Academic environments, according to Oslo Manual, (OECD, 2018), can be considered stimulators of innovative performance, as they focus on stimulating the creation, share and application of knowledge.

A database on research groups is the Statistics Summary from RGD. The Statistics Summary is an instrument that reports and compiles data and information and provides an overview on the installed capacity of research in Brazil (CNPq, 2019), embodying the innovative performance of PEIs. Consequently, using this base, Souza and Castro (2016) verified that the innovative performance of PEIs is related to the amount of PhDs and to the relationships between research groups and firms. With the same base, but through a perspective of remuneration resulting from these relationships, Rapini, Oliveira and Silva (2016) identified the types of remuneration found in the relation between these two spheres. With the results, the authors highlighted that the "motivation to the engagement in cooperative activities between U-F are based in access to complementary sources, knowledge and abilities sharing, as well as the risk of the research activities" (Rapini, Oliveira & Silva, 2016, p.241)

As another example of work resulted from the Statistics Summary by RGD, Souza et al. (2019) identified that the most significant remunerations to the innovative performance of public educational institutions were: 'financial resources transfer from the partner to the group', 'supply of scholarships by the partner to the group', 'transfer of material inputs to the partner's activities', 'temporary physical transfer of human resources from the group to the partner's activities', 'partnership with transfer of any type of resources in both ways' and 'other forms of remuneration that does not fit in any of the previously mentioned'. By using the Statistics Summary of RGD, the authors developed a numeric picture of research groups during the period between 2010 and 2016. The authors collected information about the total number of groups; groups by region; federative unit and big area; quantity of researchers; scientific production; technical production subdivided in software, technological production and process or techniques; groups with relationships; groups by wide area and with relationship; types of relationships; and types of remuneration (Souza et al, 2019).

Shortly, according to the authors, there was an increase of 37% of the quantity of research groups in Brazil, compared to 2010, in other words, there were more than ten thousand groups. The regions North, Northeast, Central-West presented the highest rates of research groups increases: 66.22%, 52.91% and 47.53%, respectively. There was an increase of 7% in the total of national scientific production, however the technological production (software production, technological products and process with and without patents/register/catalogue), showed a decrease of 3%. Regarding the number of researchers, there was an increase of 54.83%, while the number of PhDs researchers increased to 59.24% (Souza et al, 2019). These authors associate this increase as a positive influence factor in the innovative performance of the country.

3 Method

To achieve this research's aim a descriptive, quantitative and documental research was developed, based on data made available by Research Groups Directory of Brazil (RGD) (CNPq, 2019). The RGD refers to an inventory that harbors information about active scientific and technological research groups in Brazil. The collected data refers to researchers, students and technicians of the groups, and to active research lines. RGD also presents the specific knowledge, scientific, technological and artistic productions and data regarding the interactions between research groups and other institutes, specially with the productive sector (CNPq, 2019).

The RGD data show information about the situation of scientific-technological Brazilian activities (CNPq, 2019), which reaffirm this database's relevance to the context of this investigation. By harboring information pertinent to relationships between research groups and firms, this base becomes the main source on it, being chosen for the present research. It is highlighted, therefore, that this information is not found in other databases.

To obtain the types of relationships between research groups and firms that contribute the most to the innovative performance of PEIs, the tabular plan of RGD was used. The tabular plan aims to set a quantitative profile of research in Brazil, organized in tables in which the user dynamically perform construction and view configurations (CNPq, 2019). However, with the tabular plan being discontinued by CNPq after 2010, the last available census of 2010 was elected to be used. The use of this data is justified by considering it as an extensive set of information that originated from the registration of research groups in CNPq directory, from Lattes database and from CAPES gathering system. Furthermore, Souza et al. (2019) and Souza and Castro (2016) also used this same census in their research on innovative performance.

The main data collected from the tabular plan are: i) educational institution; ii) total groups by educational institution; iii) technical production by educational institution; and iv) types of relationships (Rel) by educational institution (14 types, represented in Table 1). To outline the research sample, 304 public and private institutions registered in the tabular plan were identified. With the purpose of verifying which institutions were public, the e-MEC Register of Institutions and Courses of Higher Education was consulted. Only 118 (39%) of these 304 institutions, composed the final sample of public institutions. Information regarding the administrative category (Federal, state and municipal) and the academic organization (universities, institution, college, center or others) of these public education environments was also added.

As the sample was defined, it was possible to develop multivariate statistics, using the statistical software Statistical Package for the Social Sciences (SPSS). To start the set of analyses, the reliability of the data collected was checked through Cronbach's Alpha. Cronbach's Alpha is composed as a measure of reliability that assesses the consistency of the entire scale ranging from 0 to 1, where the value of 0.60 is considered the lower limit of acceptability (Hair Junior, Black, Babin & Anderson, 2009).

Table 1. Main Types of Relationships between Research Groups and Firms.

Types of Relationships	Quantity of Groups
Rel1 - Scientific research without consideration of immediate use of results	9232
Rel2 - Scientific research with consideration of immediate use of results	8151
Rel3 - Non-routine engineering activities, including the development of a serial head prototype or pilot plant to the partner	1492
Rel4 - Non-routine engineering activities, including the development / manufacture of equipment to the group	1751
Rel5 - Non-routine software development by the partner to the group	1202
Rel6 - Software development by the partner to the group	1249
Rel7 - Transfer of technology developed by the group to the partner	4238
Rel8 - Transfer of technology developed by the partner to the group	3762
Rel9 - Technical consulting activities not covered by the other types	4159
Rel10 - Provision, by the partner, of material inputs for the group's research activities without being linked to a specific project of mutual interest	5096
Rel11 - Provision, by the group, of material inputs for the partner's activities without being linked to a specific project of mutual interest	1652
Rel12 - Training of partner's team by the group including courses and in-service training	4033
Rel13 - Training of groups' team by the partner including courses and in-service training	3573
Rel14 - Other predominant types of relationship that do not fit into any of the previous	6553

Source: CNPq (2019).

After checking the data's reliability, a correlation analysis was performed. The purpose was to measure the rate of association between the variables. Therefore, it was necessary to choose the most appropriate correlation test through the normality test. Hence, the Kolmogorov-Smirnov test was performed, which is indicated when there are more than 30 samples in a database (Mendes & Pala, 2003). With this evaluation, the 14 relationships present a p value lower than the meaningfulness value of 1%, pointing out that all these variables show non-normal distribution. Accordingly, the non-parametric correlation of Spearman is inferred to be the most indicated (Mukaka, 2012). For Bauer (2007), this type of correlation should be developed in order to replace the Pearson's coefficient, when the quantitative data show a joint distribution different from a normal bivariate distribution.

Subsequently, the cluster analysis was applied, through the Ward Hierarchical model based in Maroco (2010) and Malhotra (2011). According to Maroco (2010), this analysis is an exploratory technique that allows clustering subjects in uniform groups relatively to one or more common features. According to the same author, each observation belongs to a specific group that resembles all other observations of the same cluster, becoming distinct from the other groups' observations. The Ward Method, according to Hair Junior et al. (2009), implies that the distance between two clusters is the sum of the squares between these two sets. Hence, this method aims to minimize the square of the Euclidean distance to the averages of the clusters (Malhotra, 2011). After defining the clusters, the ANOVA test was performed. This test's aim is to probe the cluster's profiles. According to Maroco (2010), the ANOVA (Analysis of Variance) is instrumental to compare measures of two or more populations from which random and independent samples were taken.

As a last analysis, in order to identify the relationships between research groups and firms that contribute the most to the innovative performance, the discriminant analysis was applied. The discriminant analysis is a technique where the dependent variable is categorical, or qualitative, and the independent variables are metric, or quantitative (Hair Junior et al., 2009; Malhotra, 2011). To apply this technique its assumptions were met. Accordingly, it sought to verify the presence of outliers and homogeneity of variance-covariance matrices. To verify the outliers, the Mahalanobis Method was used. This method points out atypical observations in the sample (Hair Junior et al., 2009). As a result, the method showed the presence of outliers. Albeit, after analyzing each atypical observation, it was decided to keep the sample, under the justification that its exclusion would affect the final results, that is, in Cluster 3. In other words, important institutions with high U-F interaction would be taken out from the sample, for example the University of São Paulo. Keeping the PEIs with high interaction reveals the entities with higher innovative performance potential.

The Levene Test was applied in the analysis of the matrix homogeneity of variance-covariance. This test evaluates if the variances of a single metric variable are the same in any number of groups (Hair Junior et al., 2009). To operate it, it was set as the null hypothesis that the clusters were uniform. The Levene test results were not significant, discarding the alternative hypothesis that at least one of the clusters presented a different variance. Hence, there was not enough statistical evidence to affirm the clusters had different variances.

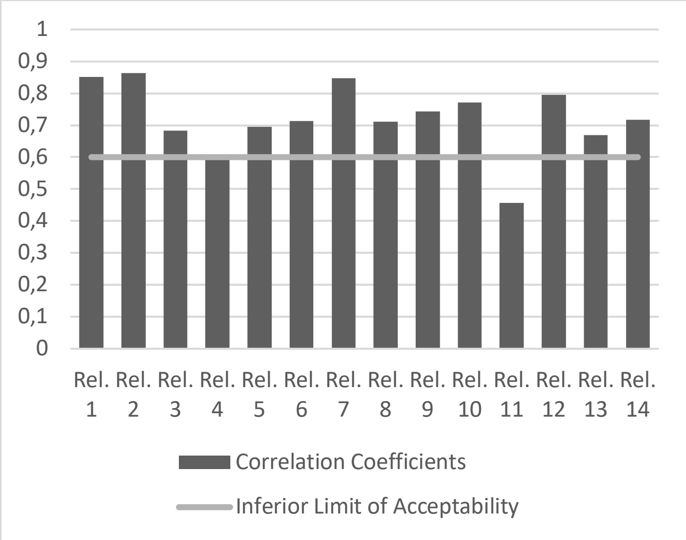
Based on these tests, it was possible to proceed to the discriminant analysis. So the 3 clusters were considered as dependent variants and, as independent variants, the 14 types of relationships, in order to evidence, between these variables, the most significant. The Stepwise Method (by stages) was chosen, because it is the most common and estimates the discriminant functions. In other words, the independent variables enter sequentially according to the discriminatory power that they add to the accuracy of a group's relevance.

4 Relationships of Research Groups involving Firms and Innovative Performance

Para iniciarmos a aplicação das técnicas To start the implementation of multivariate techniques, it was necessary to verify the reliability of the collected data from the Tabular Plan. Therefore, the Alpha Cronbach analysis points out the value of 0.903, a value that, according to Hair Junior et al. (2009), is above the lower limit of acceptability. A high data reliability was, consequently, verified.

Subsequent to the implementation of statistical techniques, the Spearman Correlation was conducted. The correlation was performed on the association of 14 types of relationships and the innovative performance (technical production). Based on the results, Figure 1 was developed, showing strong positive correlations (between 0.7 and 0.9) for relationships 1, 2, 6, 7, 8, 9, 10, 12 and 14; moderate positive (between 0.5 and 0.7) for relationships 3, 4, 5 and 13; and weak positive for relationship 11, as indicated by Mukaka (2012). Only relationship 11 stood under the lower limit of acceptability, with the value of 0.456. However, it was decided to keep it, since it was understood that it could be important to the study.

Figure 1. Correlation coefficient of the types of relationship with innovative performance.



Source: Developed by the authors.

According to Figure 1, the results point out that the 14 relationships have a positive association with the innovative performance of PEIs, similar to Souza and Castro's (2016) study. This study verified that, in addition to the PhDs quantity, the quantity of relationships between research groups and firms assume high discriminatory importance to the promotion of innovation at those institutions. After identifying the relation degree of the relationships with the innovative performance, the Cluster Analysis was applied to the relationships' data. The aim of this application was to verify the clusters created by the quantity of relations obtained between research groups and firms. This application was based on the work of Souza and Castro (2016). However, it is important to mention that this study did not show which institution presents a higher or lower quantity of relationships; and the types that contribute to the innovative performance of PEIs. As a result three clusters were formed: Cluster 1 showed 84 PEIs (71% of total), Cluster 2 showed 25 PEIs (21% of total), and Cluster 3 showed 9 PEIs (8% of total).

To deepen these clusters' profiles, the ANOVA was applied. The ANOVA test relates the clusters to the administrative categories, academic organization, quantity of research groups, technical production and quantity of relationships. As the null hypothesis, it was set that there is no distinction between the clusters. The results revealed that the variables "quantity of groups", "technical production" and "quantity of relationships" were relevant to 5%, according to Hair Junior et al. (2009). Table 2 presents the relation of these variables and the relationship between research groups and firms. The other variables were dismissed, as they were not significant.

Regarding the presented results, it was possible to establish the predominant profile of each cluster. Cluster 1 is composed by institutions with a low quantity of research groups, technical production and relationships. It was consequently named 'Low average of relationships between research groups and firms'. In Cluster 2 the profile mostly corresponds to institutions with a high quantity of groups, but a low technical production and average quantity of relationships. This cluster's label was named as 'Moderate average of relationships between research groups and firms'. Lastly, Cluster 3 is composed of institutions with a high quantity of groups, technical production and relationships. It was named as 'High average of relationships between research groups and firms'.

Table 2. Relationship Clusters' predominant profiles.

	***Cluster* 1**	***Cluster* 2**	***Cluster* 3**
Number of Public Educational Institutions	84 Institutions	25 Institutions	9 Institutions
Quantity of groups	Low quantity of research groups[1]	High quantity of research groups[2]	High quantity of research groups[2]
Technical Production	Low technical production[3]	Low technical production[3]	High technical production[4]
Quantity of Relationships (Total of 14 relationships)	Low quantity of relationships[5]	Average quantity of relationships[6]	High quantity of relationships[7]

Note. (*) The values were classified based on the cluster analyses; [1]lower than 247 research groups; [2]above 247 research groups; [3]lower than 446 technical production per PEI; [4]above 446 technical production per PEI) regarding 17 PEIs (15% of total); [5]An average of 23 relationships per institution.; [6] An average of 134 relationships per institution; [7] An average of 490 relationships per institution.
Source: Developed by the authors**.**

Some inferences based on the results mentioned above are presented. By considering the clusters' profile along with the Spearman correlation and the results of Souza and Castro (2016), the direct association between technical productivity and relationships between research groups and firms can be validated. It was noted that only one group, Cluster 3, presents a high quantity of relationships, where 9 institutions have a high quantity of public-private partnerships. The other 109 Brazilian higher education institutions have low or average quantity of partnerships between research groups and firms, resulting in lower quantity of technical productions. Such results validate the affirmative that, in fact, the public-private partnership optimize the technical production and the innovative performance of the institutions (Quandt, Bezerra & Ferraresi, 2015; Rapini, Oliveira & Silva 2016; Souza & Castro, 2016; Souza et al., 2019). Table 3 demonstrates the PEIs ranked at each cluster.

Table 3. Ranking of PEIs according to Clusters' Relationships.

Clusters	**Institutions**
Low average of relationship between research groups and firms	UFAC; IFAL; UFAL; UNCISAL; UNIFAP; IFAM; UEA; UFAM; IFBA; UEFS; UESB; UESC; UFBR; IFCE; UECE; URGA; UVA-CE; IFB; IFG; IFGoiano; UEG; UEMA; UFMA; IFMT; UNEMAT; UEMS; UFGO; UFMS; UEMG; IFSEMG; IFTM; UEMG; UFJF; UFSJ; UFTM; UFVJM; UNIFALMG; UNIFEI; UEM; UENP; UEPG; UNESPAR; UNICENTRO; UEPB; UFPB; IFPA; UEPA; UFOPA; UFRA; IFSertõesPE; IFPE; UFRPE; UNIVASF; UPE; IFPI; UESPI; UFPI; UERN; UFERSA; FURG; IFFarropilha; IFRS; UNIPAMPA; CEFET/RJ; IFRJ; IME; UENF; UFRRJ; UNIRIO; IFRO; UNIR; UFRR; IFCatarinense; IFSC; UNOESC; IFS; UFS; FAMERP; ITA; UNITAU; UFT; e UNITINS.
Moderate average of relationship between research groups and firms	UFBA; UNEB; UFC; UNB; UFG; UFMT; CEFET/MG; UFLA; UFOP; UFU; UEL; UNIOESTE; UTFPR; UFCG; UFPA; UFRN; UFPEL; UFSM; UERJ; UFF; FURB; UDESC; UFSCAR; UNICAMP; e UNIFESP.
High average of relationship between research groups and firms	UFMG; UFV; UFPR; UFPE; UFRGS; UFRJ; UFSC; UNESP; e USP.

Note: The PEIs were classified according to their Federative Unit.

Source: Developed by the authors.

On the analysis of Table 3, it is verified that the Federal Universities from Minas Gerais, Paraná, Pernambuco, Rio Grande do Sul, Rio de Janeiro and Santa Catarina, and the State ones from São Paulo were the ones with the highest quantity of relationship. Therefore, it was indicated the need for future research that analyzes these institutions and the reason why they present more relationships regarding innovative performance. Finally yet importantly, it was noted that, except for UFV, the other institutions are from Brazilian state capitals. As such, it is indicated to understand how location affects the innovative performance of educational institutions.

After setting the PEIs' clusters, the aim was to identify the relationships that most interfered with the cluster's distinction. To achieve this, the discriminant test was applied. It was set, therefore, as a dependent variable, the three obtained clusters and, as independent variables, the 14 types of relationships. It was accepted as the null hypothesis the non-distinction between the clusters (low, moderate and high average of relationships). The results of the discriminant test presented the rejection of the null hypothesis, indicating that there are differences between the clusters, with 1% of significance level by the Wilks' Lambda test. The discriminant test revealed that the relationships that most discriminate the clusters, according to Stepwise Method, are, in descending order: relationship 7 (Technology transfer developed by the group to the partner), relationship 5 (Non-routine software development by the partner to the group); relationship 4 (Non-routine engineering activities including the development/manufacture of equipment to the group); and relationship 2 (Scientific research with consideration of immediate use of results).

The discriminant function showed a Canonical Correlation Coefficient of 0.941 for the first discriminant function; 0.494 for the second one, which, in other words, indicates a high degree of association between the function and the analyzed clusters. Finally, the results also showed that 94.9% of PEIs were correctly classified inside the clusters, which means a high percent of classification consistency.

These results complement the research of Rappini and Righi (2007). In its turn, the authors verified that there was a concentration of mutual interest relationships (74% and 92% respectively), from the universities to the firms during the period between 2002 and 2004. This result contributes to the relevance of relationships 7 and 2 and their discriminant function values. Rapini and Righi (2006, 2007) also showed that the most frequent U-F relationships were: scientific research with considerations of immediate use, with 30.3% (relationship 2); transfer of technology developed by the group to the partner, with 17% (relationship 7) and scientific research without considerations of immediate use of the results, with 15.7% (relationship 1). On the other hand, among the most frequent relationships between firms and research groups were: relative leadership of technology transfer, in 2004 (relationship 8), in the face of non-routine engineering activities in 2002, associated to the early stages and definition of projects (relationship 4); and the relationship of software development that obtained the highest expressiveness by research groups to the firms (relationship 6).

Summarizing, it was noted that the relationships discriminated in this study are similar to those of the studies above mentioned. However, the only different relationship was the development of non-routine software by the partner to the group (relationship 5), in opposition to the development of non-routine software by the group to the partner (relationship 6). This divergence is justified by understanding that this result could be caused by the tabular plan update. Lastly, Table 4 demonstrates the relation between the clusters and the discriminated types of relationship.

Table 4. Relation between the Clusters and the Most Significant Relationships (by Numerical Order).

	***Cluster* 1**	***Cluster* 2**	***Cluster* 3**
Rel. 2	High quantity of PEIs with low relationship rate 2 (from 0 to 44 rel.)	Average quantity of PEIs with average relationship rate 2 (from 11 to 72 rel.)	Low quantity of PEIs with high relationship rate 2 (from 112 to 264 rel.)
Rel. 4	High quantity of PEIs with low relationship rate 4 (from 0 to 2 rel.)	Average quantity of PEIs with average relationship rate 4 (from 0 to 4 rel.)	Low quantity of PEIs with high relationship rate 4 (from 3 to 27 rel.)
Rel. 5	High quantity of PEIs with low relationship rate 5 (from 0 to 1 rel.)	Average quantity of PEIs with average relationship rate 5 (from 0 to 7 rel.)	Low quantity of PEIs with average relationship rate 5 (from 1 to 10 rel.)
Rel. 7	High quantity of PEIs with low relationship rate 7 (from 0 to 16 rel.)	Average quantity of PEIs with average relationship rate 7 (from 4 to 39 rel.)	Low quantity of PEIs with high relationship rate 7 (from 44 to 93 rel.)

Source: Developed by the authors.

It was noted that the clusters are different in terms of the quantity of relationships obtained in the listed ones (2, 4, 5 e 7). In other words, the cluster with low relationship rate between research groups and firms shows few relationships of types 2, 4, 5 e 7. Similarly, the cluster with average relationship rate between research groups and firms shows a moderate quantity of these types of relationships. Finally, the cluster with high relationship rate between research groups and firms shows a high quantity of relationships of these types, mainly the 2, 4, 5 and 7. The only exception was relationship 5, regarding high relationship rate between research groups and firms (Cluster 3), showing an average quantity of relationship 5. Hence, the results infer that the greater the frequency of relationships 2, 4, 5 and 7, the better it would be the position of PEIs in the clusters and as a high innovative performance institution. This result is also confirmed by research of Rapini and Righi (2006; 2007).

Summarizing, the results demonstrate that certain types of U-F relationships have higher influence on the innovative performance of PEIs. These relationships are present, mainly, in the PEIs of the third cluster, which show, in fact, higher quantities of interaction between the productive sector and universities. Lastly, the findings mentioned can be a source of inspiration for many authors in this context, as it will be mentioned at the final considerations section.

5 Conclusion

According to the aim of identifying the relationships that contribute the most to the innovative performance of PEIs, three institution groups were found that show low, moderate and high average of Relationship between research groups and firms. Based on these, it was verified that the relationships of type 7 (Transfer of technology developed by the group to the partner), 5 (Development of non-routine software by the partner to the group), 4 (Non-routine engineering activities, including development/manufacture of equipment to the group) and 2 (Scientific research with considerations of immediate use), respectively, were the most relevant relationships, since they optimized the innovative performance of Brazilian PEIs. These results emphasize the claim that, by supporting certain types of relationships, it is possible to have an increase in PEIs' innovative potential. This data corroborates the one pointed out by Schaeffer, Ruffoni and Puffal (2015) which reinforces the idea of transcending the "interaction points" between universities and firms. To the authors, there is a need to not only value this relationship quantification, but also the quality of these interactions so they can generate knowledge and innovation dissemination.

However, as much as supporting some relationships can lead to increased innovative performance, it is emphasized that the relationships by themselves are not the single factor to obtain such performance. Besides institutional aspects, such as those highlighted on the Triple Helix theory, it is also necessary that the Brazilian government support the public-private partnership, developing actions to promote and support it. The results must be evaluated with caution as, according to Rapini, Oliveira and Silva (2016), there are different performances of the research groups in Brazil. In addition, Souza and Castro (2016) identified that, besides the relationships between research groups and firms, the variable "quantity of PhDs" affects innovative performance.

As the first limitation of this study is the fact that data of the tabular plan is only available up to 2010. The contact with CNPq revealed that this absence of update was not casual. However, regarding the great contribution verified by the collection of data and reinforced by these study results, the importance of tabular plans to understand the research development in Brazil is highlighted. It would be a great value if CNPq rethinks the decision of suspending the tabular plan, since the census by itself does not add value to this study regarding innovative potential. The second limitation is associated with the fact that RGD does not present, categorically, better details regarding the types of relationship, making it difficult to deepen the understanding of interactions. Finally, as the last limitation, the absence of additional innovation bases that could subsidize the results obtained here is pointed out. The next topic describes new conclusions showing the implications and agenda for future studies.

6 Implications and Future Research

As theoretical contributions, it is highlighted that this study results describe the operation of the Triple Helix. The Triple Helix operation reflects current structures with complex roles and relations, which covers highlighted gaps in critics to the model (Mineiro, Souza & Castro, 2018). Furthermore, the results point out key aspects to each of the three actors of Triple Helix. Regarding the government, the need for specific definitions of national support to encourage Triple Helix is reinforced, particularly the specific U-F interactions. Hence, with the absence of definitions to support the results from U-F interactions, it is not possible to mitigate the benefits. Accordingly, studies can analyze the current public policy actions regarding the relationships highlighted here, pointing out gaps and new practical orientation. About the productive sector, the findings show that U-F interactions can sustain improvements on regional, national and international competitiveness. These results can be discussed in light of open innovation. Finally, some questions related to the universities still need to be answered, such as: how can these relationships be handled as an open innovation source? And how can both parts, U-F, benefit in open innovation analyses?

As social contributions, it is highlighted that these results can support the development of innovations that generate solutions to environmental and social issues. Besides that, by reinforcing the importance of the University for human and intellectual development, it has the opportunity, with the results shown here, to improve the actions of universities. As practical contributions to the PEIs, it is argued that the results found can help them determine innovative ways that should be based on development and technology transfer and on conducting research oriented to practice. Consequently, it is possible for universities and research institutions to better support definitions of essential expertise (training of qualified labor) through the development of research groups, reinforcing their benefits in academic, scientific, professional, social and operational terms. Lastly, practical contributions can arise from analyses of key aspects of relationship forms, highlighting reviews and improvements of the current laws regarding interactions between the public and private sectors.

Besides the indications for future research mentioned above, the new verification of the scope of this work is named, in case the tabular plan is updated. Due to the limitation of categorical specifications of the relationships, it is indicated to understand, qualitatively, the perspective of the groups' manager, pointing out their difficulties, needs and opportunities of interaction. Finally, the results are yet to be studied regarding the models of Quadruple (society) and Quintuple Helix (environment).

Acknowledgements

The authors would like to thank the Federal University of Lavras (UFLA), the University of São Paulo (USP), the Coordination for the Improvement of Higher Education Personnel (CAPES), and the Minas Gerais Research Funding Foundation (Fapemig) for their support.

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Authors' contribution:

Author 1: set the aim and research method, took part in the theoretical background, managed the statistical techniques and developed the result analysis.

Author 2: set the research's aim, took part in the theoretical background and developed the conclusion.

Author 3: supervised the work, reviewed the statistical techniques and proposed improvements.