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Analysis of scientific research groups with greater productive applicability in Brazil: capacities and interactions with firms[1]

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Abstract. This paper analyzes the capacities of BR Survey Research Groups in generating science and technology, and how these groups may be associated with university-firm interactions. To this end, we perform a classification based on the diagram proposed by Stokes (2005), using the qualitative comparative analysis (QCA) statistical technique. As a primary result, we find that scientific and technological capacity on the part of the research groups is not a necessary condition for interactions with companies. Indeed, some research groups without high scientific and technological capacity make more interactions (in terms of the total amount) and yield similar values in the analysis (relative to the number of researchers) in comparison with the most qualified groups: those located in Pasteur's quadrant.

Keywords: Academic-industrial collaboration; science and technology; scientific research; research workers; technological innovations; Brazil.

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Acronyms

CAPES	Council for the Improvement of Higher Level Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível de Superior)
CNPQ	(National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico)
ISI	Institute for Scientific Information
NIS	National innovation system
QCA	Qualitative comparative analysis
RGD	Research group directory (diretório de grupos de pesquisa)
R+D	Research and development
ST&I	Science, technology, and innovation
SciELO	Scientific Electronic Library Online
U-F	university-firm

1. Introduction

Competition compels capitalist firms to grow. Two key aspects in achieving growth are the construction of aptitudes and the ability to learn. Accordingly, the Schumpeterian perspective stresses this construction as a way of creating competitive asymmetries based on product differentiation and the establishment of more efficient processes.

By broadening the availability of knowledge and capacities, firms increase their opportunities for innovation; this is possible, for example, through efforts to increase scientific and technological understanding. As Rosenberg (1990) notes, firms strive via their own resources to carry out basic as well as applied research activities; and, striving for growth, they form strategic alliances by expanding their learning capacity.

Universities are essential partners of firms because they are key institutions in the innovation system, given their creation and dissemination of new knowledge and inventions by way of basic and applied research, development, and engineering (Mowery & Sampat, 2005; Mazzoleni, 2005; Mazzoleni & Nelson, 2005). The generation and dissemination of science and technology has received special attention in the international and national literature, both in terms of creating new spin-off businesses and increasing the capabilities of already established firms.

In this regard, academic capabilities merit the attention of public policy makers, given that scientific and technological capacities tend to be important delimiters of efficiency in interactions with firms. An understanding of this allows articulations and alliances to be fostered between academia and firms, increasing capacities in a highly competitive environment.

Our objective here is to contribute to this area of investigation by analyzing universities (at the level of their research groups) and their science and technology output, as well as their interactions with firms, making comparisons between scientific and technical capabilities and the capacity for interaction with firms on the basis of the quadrants proposed by Stokes (1997/2005). To this end, we use data from the BR Survey, conducted in 2008 with the participation of research groups registered in the research group directory (diretório de grupos de pesquisa, DGP) of the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPQ).

This study is divided into three sections in addition to this introduction and the final considerations. In section two, we describe the role of universities in the innovation system, as well as the specificities of university-firm (U-F) interaction in Brazil. In section three, we present the database and debate the methods of analysis. In section four, we discuss the results we obtained through our analysis.

2. Universities: scientific and technological capacities

Knowledge generation is a dynamic and interactive process. The main actors in this process are universities (Arocena & Sutz, 2001), which are fundamental to both the creation and dissemination of new knowledge and technologies by way of basic and applied research, development, and engineering. Therefore, universities serve as incubators of new ideas that can be transferred to new actors in the innovation system – by forming a network of interactions – and applied to production processes, often leading to innovations (Chiarini & Vieira, 2012a).

Thus, the recognition of the role of universities in creating new knowledge has stimulated the production sector's interest in accessing them. The debate on U-F interaction is rather extensive in the international[2] and national[3] literature and, other variances notwithstanding, does not reduce the role of universities to that of merely supporting the technological development of certain sectors of economic activity, instead placing equal weight on their function as basic knowledge producers (Chiarini & Vieira, 2011).

U-F interaction – as well as research and development (R+D) collaboration, for instance – is justified as a means of reducing the uncertainties inherent to the innovation process (Tether, 2002), diluting risks related to innovative activities (Hagedoorn, Link, & Vonortas, 2000). The relationship can benefit companies by facilitating the development of capacities, learning, and acquisition of knowledge and technologies (Marques, Freitas, & Silva, 2007), thus contributing to the completion of industrial projects and/or facilitating the implementation of new projects.

Although U-F interactions have the potential to create and disseminate new knowledge and eliminate the risks associated with innovative activities, according to Arza (2010), they can also lead to the privatization of public

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[2] See, for example: Harmon, Ardishvili, Cardozo, Elder, Leuthold, Parshall, Raghian, & Smith (1997); Friedman & Silberman (2003); Shane (2002); Wright, Birley, & Mosey (2004); Markmana, Gianiodisa, Phanb, & Balkinc (2005); Arza (2010).

[3] See, for example: Albuquerque (1999); Dagnino (2003); Cruz (2004); Albuquerque, Silva, Rapini, & Souza (2005); Rapini & Righi (2006); Rapini (2007a, 2007b); Renault, Mello & Carvalho (2008); Póvoa & Rapini (2009); Rapini, Suzigan, Fernandes, Comingues, Carvalho, & Chaves (2009); Esteves & Meirelles (2009); Mello, Maculan, & Renault (2009); Suzigan & Albuquerque (2009); Chiarini & Vieira (2011, 2012a, 2012b); Chiarini, Oliveira, & Silva Neto (2013); Chiarini, Rapini, & Vieira (2014); Rapini, Oliveira, & Silva Neto (2014); Rapini, Chiarini, & Bittencourt (2015); Brito, Santos, Kruss, & Albuquerque (2015); Schaeffer, Ruffoni, & Puffal (2015); Rapini, Oliveira, & Caliari (2016); Caliari & Rapini (2017); Caliari, Santos, & Mendes (2016).

research outcomes and color the research agenda (in the interests of private actors), distancing the process from the pursuit of more socially desirable knowledge. Thus, the production of new technical-scientific knowledge at universities casts aside the function of mere "enlightenment" without economic ends, to become more oriented towards creating economic value and expressing capitalist competition.

Although the role of universities in creating both basic (pure) and applied science is now recognized, for a long time the two approaches were regarded as conceptually distinct. The former has the objective of expanding comprehension of phenomena in a given scientific field; that is, it ought to be discharged without practical or profit-making ends, inspired by the pursuit of understanding alone. Known as natural philosophy, its results were centered on the discovery of metaphysical truths about the nature of the universe (Noble, 1979). On the other hand, practical men – "technologists" –- had little to no concern for abstract theories, their interest being centered more on utility and profits. Therefore, applied science was seen to be inspired by considerations of use; that is, oriented to a certain specific need to solve practical problems. According to Nelson (1959), applied research was unlikely to shift scientific paradigms, except by mere chance, and it was through basic research that additions were made to the store of knowledge.

The categorical separation of basic and applied research led, erroneously, to the division of science and technology: science as the sole outcome of pure research, and technology as the result of applied research. This "divorce" led to a conception of basic research as the initial stage of the scientific development process, giving way to applied research and then to innovation. The process was known as a "linear model" (science-pushed), and has been widely criticized for its inherent lack of feedback; that is, applied research does not influence basic research, and neither marketing nor users influence basic or applied research (Kline & Rosenberg, 1986).

Despite such heavy criticism, the model served as the basis for countless public policies, and was even used as justification for public funding of scientific research and as an incentive for productive-sector investment in R+D. The premise was that the results of basic science would materialize once they were turned into technological innovations by way of technology transfer processes. From this perspective, science was regarded as the main source of technological innovation.

The distinction between science and technology led to the conclusion that science was only developed at universities and public research laboratories, while it was scientists working for private firms who were concerned with developing technology.(Nelson, 1982) However, challenging this conception, there are many examples throughout history of fundamental advances being made while working on practical or applied problems. Indeed, there is concrete evidence to show that both the pursuit of understanding and its application can influence research choices. The emblematic case is that of the French scientist Louis Pasteur, who:

> […] pursued a fundamental understanding of the processes of disease and other microbiological processes that he gradually discovered as he progressed through the successive studies of his notable career. But nor is there any doubt that he sought such understanding to achieve the applied objectives of preventing deterioration in the production of vinegar, beer, wine and milk, and to defeat flacherie in silkworm, anthrax in sheep and cattle, and rabies in animals and human beings. […] as Pasteur's studies became progressively more fundamental, the problems chosen by him and the lines of research adopted were progressively more applied. […] Pasteur […] never carried out a study that was not applied, while he shaped a completely new branch of science (Stokes, 1997/2005, p. 31).[4]

There are other examples. In the field of economics, John Maynard Keynes had a strong desire to understand macroeconomic dynamics at a fundamental and basic level (to contribute to the advancement of economic theory), but he also sought to overcome the economic depression of 1921 by coming up with practical solutions to real problems (Stokes, 1997/2005).

These cases fit within what Stokes (1997/2005) calls Pasteur's quadrant. Drawing on historical examples, Stokes conducts a bidimensional analysis of research objectives; that is, to expand knowledge for practical ends. Stokes plots two axes: a vertical one, representing the pursuit of pure understanding, and a horizontal one, taking into consideration how knowledge will be used. On this basis, he proposes four different quadrants: those of Pasteur, Bohr, Edson, and Ruetsap.

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[4] The original text in Portuguese is: "buscava um entendimento fundamental dos processos de doença e de outros processos microbiológicos que ia descobrindo, à medida que se movia pelos estudos sucessivos de sua notável carreira. Mas também não existem dúvidas de que ele buscava tal entendimento para alcançar os objetivos aplicados de prevenir a deterioração na produção de vinagre, cerveja, vinho e leite, e de vencer a *flacherie* no bicho-da-seda, o antraz no gado ovino e bovino, a cólera no frango, e raiva em animais e seres humanos. […] à medida que os estudos de Pasteur se tornavam progressivamente mais fundamentais, os problemas escolhidos por ele e as linhas de investigação adotadas tornavam-se progressivamente mais aplicados. […] Pasteur […] nunca realizou um estudo que não fosse aplicado, ao mesmo tempo que dava forma a todo um novo ramo da ciência" (Translation by *Apuntes*).

Pasteur's quadrant refers to the scientific fields dedicated to solving specific practical problems and furthering understanding at the same time. As such, it concedes the possibility that significant advances in scientific knowledge can also have practical value. New knowledge can serve as an input for future research. Therefore, basic research can create substantial externalities for applied research.

This quadrant provides theoretical support for the idea that the progress of knowledge is founded on basic research, which in turn is inspired by its utilization By placing knowledge in "motion" and meeting social demands, this conceptualization can act as the basis for a new understanding between the scientific and political communities. A breakdown of the other three quadrants proposed by Stokes (1997/2005) is provided in Table 1.

Table 1
Quadrant model of scientific research

		Is the research inspired by usage considerations?	
		No	Yes
Is the research inspired by the pursuit of fundamental knowledge?	Yes	Pure basic research (Niels Bohr's quadrant)	Basic research inspired by use (Louis Pasteur's quadrant)
	No		Pure applied research (Thomas Edison's Quadrant)

Source: Stokes (1997/2005, p. 118).

Edison's quadrant considers applied research as that which aspires towards technological development without pursuing advances in understanding. Such research possesses some scientific importance, and science is used with strategic perspectives. And oft-cited example is the electric light system developed by Thomas Edison.

In turn, Bohr's quadrant represents the utilization of basic research with no immediate application. There is no commitment to developing a specific product or process. The objective is to interpret natural phenomena. One such example is the research of Niels Bohr, whose contributions to quantum theory earned him the Nobel Prize in Physics in 1922.

Finally, Ruetsap's quadrant is the anti-science quadrant (the blank quadrant shown in Figure 1); that is, it represents societal needs that are not covered by the other quadrants. It is used to classify social, scientific, and technological phenomena in areas outside academia, as well as research motivated by the curiosity of the researcher; Stokes (1997/2005) defines these as "particular" events, and cites birdwatching as an example.

Table 1 can be used to classify individual researchers and the research groups in which they are active, according to their scientific and technical capacities; that is, their capacity to further basic knowledge and their capacity to carry out applied research with the aim of achieving technological developments (Table 1). Thus, it is expected that the greater the scientific and technological capacity, the greater the interactions between basic and applied research; that is, between universities and the productive sector. In this way, according to Stokes's (1997/2005) logic, if there is a high level of scientific capacity but a low level of technological capacity, few interactions between universities and firms will be expected. The same is expected to hold true if there is a high level of technological capacity and a low level of scientific capacity. Most interactions occur in Pasteur's quadrant, where there is a high level of both scientific and technological capacity.

Table 2
Classification of scientific and technological competences in the quadrants proposed by Stokes

		Is the research inspired by usage considerations?	
		No	Yes
Is the research inspired by the pursuit of fundamental knowledge?	Yes	Pure basic research Bohr's quadrant High level of scientific capacity Low level of technological capacity	Basic research inspired by use (Pasteur's quadrant) High level of scientific capacity High level of technological capacity
	No	Low level of scientific capacity Low level of technological capacity	Pure applied research (Edison's Quadrant) Low level of scientific capacity High level of technological capacity

Source: Stokes (1997/2005, p. 118); compiled by authors.

Stokes's (1997/2005) efforts to distinguish between basic and applied research notwithstanding, his main contribution lays in exposing the inadequacy of the linear model and showing that pure and applied science are practices with different characteristics. For Dasgupta & David,(1994), the distinction between basic and applied research on the basis of their respective objectives is irrelevant. For them, the difference resides in the social behavior of different groups of scientists in the research community. In sum, the social organization of science and technology are separate from each other.

Indeed, the main difference between these two types of research communities is not the research method, nor the nature of the knowledge obtained, nor even the source of financial resources that makes the research possible, but the behavioral norms of each community – especially when it comes to publicizing research results and the compensation system. Hence, Dasgupta & David's (1994) contribution has been to separate "academic scientists" from "industrial scientists." From their perspective, what distinguishes one group from the other is the structure of the socioeconomic rules in which the research is carried out, and what each group does with its research results. Therefore, neither the cognitive ability of each nor the research objective in question – whether to further knowledge or for practical ends – is important in this regard. This being the case, distinguishing between basic and applied research based on their objectives is inconsequential.

3. Database and methodology

3.1 Data

The DGP-CNPQ[5] began in 1992 and since then it has published a biannual census of installed research capacity in Brazil, measured by the groups that are active in each period. A research group is defined as a set of researchers, students, and technical support teams organized around the execution of research lines that follow a hierarchal law based on specialty and technical-scientific capacity. As such, the DGP-CNPQ gathers information from various institutions, such as federal, state, and private universities; research institutes; public technological institutes; public and private R+D laboratories; and non-governmental organizations permanently involved in scientific and technological research.

The information gathered, broken down over time by region, federal unit, and institution, includes: the human resources[6] that comprise the groups, such as researchers, students, and technicians; research lines pursued by the groups; areas of knowledge; sectors of activity involved; scientific and technological output of the researchers and students in the groups; and patterns of interaction with the private sector.

In 2002, the CNPQ introduced specific questions about interactions between firms and other research institutions, establishing itself as a source of information about U-F relations in Brazil. However, it should be noted that the research group leaders underestimate the number of interactions

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[5] For an in-depth analysis of the DGP-CNPQ, see Rapini (2007a).

[6] We are aware that using the number of researchers registered in the DGP-CNPQ as a proxy for the distribution of human resources in S&T can be called into question, since the number of researchers not involved in research groups, and the number of groups not registered in the DGP, is large. We are also aware that a single researcher may participate in different research groups simultaneously. However, there is no other database from where we can obtain such information. Thus, we have opted to use the DGP-CNPQ, despite these limitations.

(Rapini, 2007a, 2007b). That is, more interactions take place than those actually reported by the leaders, since, according to Rapini (2007b), there are inherent differences in the questionnaire itself and in the content of the optional answers, which can limit its completion.

Registration in the DGP-CNPQ is voluntary, but researchers are strongly motivated to participate, largely because an up-to-date curriculum vitae on research is a prerequisite for access to public financing and scientific and technological research. It should be noted that interaction with the productive sector is not a criteria used by development agencies for assessing researcher performance, which may also explain the apparent underestimation. Despite these limitations, the DGP-CNPQ universe has grown in recent years, and now covers a sizable proportion of Brazil's scientific community (Carneiro & Lourenço, 2003).

After the 2004 census, participating entities were sorted into two groups: firms,[7] and research groups affiliated with universities and research institutes. Based on this classification, a survey[8] was prepared for each of the groups and was sent to them to fill out. Its objective was to determine the characteristics of U-F interactions in Brazil. This was known as the "BR Survey" and was conducted in 2008.

The BR Survey included questions about U-F interactions, covering aspects such as:

a) Forms of interaction;
b) Outcome of the interaction;
c) Benefits of the interaction;
d) Difficulties with the interaction;
e) Channels of information; and
f) Sources of financing.

Moreover, certain characteristics of the research groups, such as scientific production, technological production, number of interactions, time active, and main scientific area of operation, were included as part of the survey.

Both the firms and the research groups answered questions about interactions that took place in the three years immediately preceding the survey. The university questionnaire was sent to the heads of the 2,151 groups

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[7] The interactions involve any type of firm registered as a legal person, whether industrial or not. The database provides only the number of interactions and it is not possible to discern the sectors involved.

[8] The survey was conducted as part of Projeto Rocks, in pursuit of common questions among members of the project (Latin America, Asia, and Africa). In the case of Brazil, a national research network was established as a means of administrating the survey. On the methodology used in the BR Survey, see: Fernandes, Campello de Souza, Stamford da Silva, Suzigan, & Albuquerque (2010).

registered in the 2004 census; responses were received from 1,005 groups, equaling a response rate of 46.7%. Meanwhile, the firm questionnaire was sent to 1,622 firms, of which 319, or 18.9%, responded.

The BR Survey provides information relevant for analyzing the characteristics of research groups in Brazil based on their science and technology output, and their capacity for interaction with the productive sector. In the next section we present exercises based on this information, taking into account approximations based on the quadrants proposed by Stokes and observations of the groups' behavior based on the major areas of scientific knowledge. First, we will introduce the methodology for the model.

3.2 Methodology

The objective of this study is to understand the characteristics of research groups in terms of their scientific and technological capacity, as well as the way in which these capacities relate to the capacity for interaction with firms, taking into account the positioning of the groups in the quadrants proposed by Stokes.

Thus, we classify the research groups in order to capture their different capacities and sort them into the four quadrants, with the aim of exploring the relationship between these scientific and technological capacities and the capacity for interaction with the productive sector. In sum, we seek to verify whether, in the Brazilian case, the research groups located in Pasteur's quadrant – with high scientific and technological capacities – are those with the greatest capacity for interaction with the other actors, as inferred by the work of Stokes.

For this exercise, we opt to use the statistical technique known as qualitative comparative analysis (QCA), commonly used in experiments in the social sciences. We selected this technique for its ability to find different patterns of behavior that lead to the same result: in this case, capacity for interaction (Rihoux & Ragin, 2009). It is therefore unnecessary to establish a single specific causal model that best fits the data, instead allowing for the identification of outliers and/or opposite characteristics that give rise to the same result, the so-called conjunctural causation (Ragin, 1987; Rihoux & Ragin, 2009).

Moreover, we take into account the ongoing discussion of causation in science, technology, and innovation (ST&I) regarding the following questions: Does science generate technology, and does this in turn generate interaction? Does interaction generate more technology? Does technology generate science? Thus, the QCA method is more appropriate than a conventional econometric model, since in this method it is not necessary to determine the causal direction, only to prove the relationship between the variables.

As to conjunctural causation, we consider the possibility that variables A, B, C, D, and E exist as possible variables that generate the same output, Y. Thus, the application of QCA can lead to the conclusion that the configuration of factors AB or ACD give rise to Y (AB or ACD → Y). Or, depending on the context, the lesser value may be important to attaining the same result: AB → Y, but also aC → Y, where [a] is the designation for values below factor [A].[9]

For the purposes of this study, we use the fuzzy QCA (fsQCA) method, which enables estimation of the membership score of a group within the interval between 0 and 1. The rule used to assess the relationship between the output and the related variables, in the case of the fuzzy method, is the inclusion ratio (Longest, Vaisey, & Fuzzy, 2008):

$$I_{XY} = \sum \min(x_i, y_i) / \sum x_i$$

where:
X denotes the configuration of the predictor (i.e., AB)
Y denotes the output
x_i defines each membership in the configuration X
y_i denotes each membership in the configuration Y.

Given the conditional probability, the closer the value of I_{XY} is to the unit, the greater the consistency of the data when it is affirmed that X is a subset that defines Y ($X \rightarrow Y$). Several methods can be used to decide which configuration of predictors X is sufficient to explain Y; we base this study on Ragin (2006), who defines a benchmark of 0.700, which means that all configurations in which $I_{XY} > 0{,}700$ are sufficient for determining the membership between X and Y.

We implement an internal minimization procedure to identify the sets of conditions that encompass all possible results. If found, these sets define the conditions X, which define Y. Finally, the model allows the best configuration (the best fit) to be presented for each observation (in the specific case of this study, the research group), considering the variables in comparison with the result Y and the other groups analyzed.

For the presentation, we perform two analyses using the QCA method. The first, Model 1, seeks to associate the results of scientific and technological

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[9] Below the minimum membership values, to be defined later.

capacities that have total values with the research group's total number of interactions; while the second, Model 2, makes the same association but with values relative to the number of researchers in the group as variables. The variables for each model are set out in tables 3 and 4.

Table 3
Variables investigated using QCA, Model 1

Model 1 Total values

Output variable

1.1 Number of interactions with the productive sector

Input variable

1.2 Publications in the Institute for Scientific Information (ISI) and the Scientific Electronic Library Online (SciELO) databases.
1.3 Applications for patents, licenses and software.(1)
1.4 Group's time in operation (stated period for which the group in the database has been active, up to 2008).

Note: (1) We use the sum of the different technological outcomes given the distinctions in their uses across research groups, without making judgements about the relevance of each one. Of the 902 groups analyzed, only eight (i.e., 0.9%) possessed the three types of outcomes, while just 29 (3.2%) held patents and licenses (outcomes normally regarded as highly correlated). Moreover, this form of measurement, which considers technology apart from expectations, does not create problems for the analysis, as we will show in the following section.

Table 4.
Variables investigated using QCA, Model 2

Model 2 Relative values

Output variable

2.1 Interactions with the productive sector per operator: total number of interactions divided by the number of registered researchers(1) in the research group

Input variables

2.2 Publications per researcher: total number of publications recorded in the ISI and the SciELO divided by the number of registered researchers(1) in the research group.
2.3 Applications for patents, licenses, and software per researcher: total number of patent, license, and software applications divided by the number of registered researchers(1) in the research group.
2.4 Group's time in operation (stated period for which the group in the database has been active, up to 2008).

Note: (*) Only researchers with doctoral and postdoctoral qualifications are taken into account.

In the two models proposed, we consider the group's operating time as a way of controlling for longevity and path dependence in technological and scientific capacities. Of the 1,005 research groups in the BR Survey, we took into account 902 (89.8%): those working in the following major areas of scientific knowledge: earth and biological sciences, engineering, and exact and Earth sciences.[10]

4. Discussion and results

Our presentation of the results takes into account two aspects: the minimum configurations found by the minimization process, and the best configurations (best fits) for each research group analyzed. As to the minimization process, the application of QCA did not find possibilities of minimum results for any of the models, so it was not possible to present any results.[11]

The non-existence of results through the minimization process gives rise to an important consideration for U-F interactions in Brazil: statistically, there are no results that define capacity for interaction. Any combination of values concerning the scientific and technological capacity of the research groups can result in high levels of interaction with firms. In sum, this means that, for example, a group with relatively low scientific capacity (indicator [s] in the model) and relatively low technological capacity (indicator [t] in the model) – located in Ruetsap's quadrant, the anti-science quadrant in Table 1 – can engage in a large number of interactions, in the same way as a combination group [ST], that is, one with high scientific and technological capacity, located in Pasteur's quadrant in Table 1. Moreover, consideration of the research group's time in operation likewise did not allow a minimum configuration, indicating the limited importance of questions related to the accumulation of scientific and technological knowledge as well.

The impossibility of analysis, given the different configurations, leads to high levels of interaction and opens up a second analytical possibility: the observation of the configurations that arise in each research group. In this analysis, we consider the methodology's approximations to the theoretical positioning of the quadrants. Given the definitions of technological and scientific capacities set out in Table 2, the connections between the minimum configurations of science ([S] for high and [s] for low) and technology ([T] for high and [t] for low) with the quadrants can be understood as being the following:

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[10] We excluded research groups from the major areas of human sciences, applied social and linguistic sciences, and humanities from the analysis, because they are not considered strategic areas of relevance to industrial and technological development. However, we do not mean to imply that these disciplines are unimportant for the understanding of regional historical, economic, and social dynamics. We acknowledge the role of these areas, and it is beyond the scope of this article to defend the exclusion of lines of research that are not oriented towards the priority sectors of Brazilian industrial and technological policies; rather, here we seek only to analyze the scientific areas with the greatest productive applicability.

[11] For informational purposes, we ran the models in the statistical software Stata version 12.

Configuration St → Bohr's quadrant
Configuration ST → Pasteur's quadrant
Configuration sT → Edison's quadrant
Configuration st → Ruetsap's quadrant

Thus, we distinguished the groups according to these minimum configurations, as set out in tables 5 and 6.[12]

Table 5
QCA Models

Variables	Model 1. Total values				Model 2. Relative values			
	Bohr's Quadrant	Pasteur's Quadrant	Edison's Quadrant	Ruetsap's Quadrant	Bohr's Quadrant	Pasteur's Quadrant	Edison's Quadrant	Ruetsap's Quadrant
	St	ST	sT	st	St	ST	sT	st
Research group	192	140	124	446	189	145	120	448
Publications	10,319	12,444	156	501	10,336	12,431	169	484
Technology	0	688	374	0	0	686	374	0
Interactions with the production sector	877	935	384	2,267	858	946	378	2.281
Group's average time in operation	12.54	14.19	12.91	11.66	12.41	13.97	13.05	11.74
Publications per researcher(1)	11.52	16.39	0.40	0.26	11.96	16.01	0.20	0.14
Patents, licences and software per researcher(1)	0	1.06	0.79	0	0	1.10	0.74	0
Interactions with the production sector per researcher (1)	1.05	1.53	0.86	1.60	1.19	1.58	0.77	1.54

Note: (1) Average values.
Source: BR Survey; prepared by authors.

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[12] As stated, the group's time in operation was introduced as a control and thus was not considered in the minimum configuration of the analysis.

Table 6
Number of research groups in each quadrant, per major scientific area

Scientific areas	Model 1 Total values				Model 2 Relative values			
	Bohr's Quadrant	Pasteur's Quadrant	Edison's Quadrant	Ruetsap's Quadrant	Bohr's Quadrant	Pasteur's Quadrant	Edison's Quadrant	Ruetsap's Quadrant
	St	ST	sT	st	St	ST	sT	st
Agricultural sciences	40	22	28	110	39	24	26	111
Percentage	20.0	11.0	14.0	53.5	19.5	12.0	13.0	55.5
Biological and health sciences	53	32	29	107	62	31	31	102
Percentage	24.0	14.5	13.1	48.4	27.4	13.7	13.7	45.1
Engineering	64	55	47	157	57	55	46	160
Percentage	19.8	17.0	14.6	48.6	17.9	17.3	14.5	50.3
Exact and Earth sciences	35	31	20	72	31	35	17	75
Percentage	22.2	19.6	12.7	45.6	19.6	22.2	10.8	47.5

Source: BR (2006); compiled by authors.

For the analysis presented in tables 5 and 6, we consider the models that measure capacity by total quantity (model 1), and capacity relativized by human capital, measured by the total number of doctoral and postdoctoral researchers (model 2). Finally, we present the number of research groups per major scientific area in each quadrant. As can be noted, the results of the two models are close in terms of the capacity for interaction of research groups in Brazil, and the related variables. Taking this into consideration, for the most part our analyses will take both results into account.

In sum, the quadrants clearly correspond to the theoretical proposition. For instance, the research groups with high levels of scientific capacity and no technological capacity are located in Bohr's quadrant. In Edison's quadrant, the reverse is true: it hosts those with high levels of technological capacity and low scientific capacity. Pasteur's quadrant includes research groups with high scientific and technological capacities and, as such, can be expected to contain high capacity for interactions with the productive sector, while the reverse is the case in Ruetsap's quadrant.

Another important observation is the divergence between the scientific and the technological results. Even those groups in Pasteur's quadrant, in comparison to those with a higher technological profile, have low technological capacity in relation to their scientific capacity, which coincides with the findings of Ribeiro, Albuquerque, Franco, & Moura (2009) and of Suzigan & Albuquerque (2009).

Observing the distribution of the research groups in the quadrants gives an idea of the non-observance of a minimum configuration in the explanation of interaction with firms. The research groups are mainly located in Ruetsap's quadrant (49.7%), and have low values for scientific and technological capacities but, against expectations, exhibit a large number of interactions with firms. In relative terms, capacity for interaction is similar to that of the research groups situated in Pasteur's quadrant, even though these score well for publications and technology (total and relative); indeed, they are the groups with the highest values for these variables. Moreover, the research groups in Edison's and Bohr's quadrants also possess high relative values for interaction, despite their differences in terms of science and technology (S&T).

This result is unprecedented among studies of Brazilian academia since it shows that research groups without scientific or technological capacity have engaged in more interactions in the total quantum and in the nearby values of the analysis relative to the number of researchers, in comparison to the groups with greater capacity: those in Pasteur's quadrant. This observation illustrates the need to study the quality of U-F interactions, since the expectation is that these research groups will be less likely to achieve significant developments in the field of ST&I.

Establishing the group's time in operation does not alter the observations. Although the average operating time of the research groups in Ruetsap's quadrant is lower than the others, this does not amount to a significant difference in academic performance; this is because the difference in comparison with the research groups in Pasteur's quadrant is 2.38 years, based on the average of the two models. It is not reasonable to consider that this period can make a difference to S&T capacity for groups with an average of 11 to 14 years in operation.[13]

Finally, the observation of differences in the number of groups while taking into consideration the major scientific areas gives an indication of the minimal differentiation between these areas. It can be established that: the biological and health sciences are present in Bohr's quadrant in relatively greater proportion than the groups from the remaining areas; the research groups representing the exact and Earth sciences are proportionately greater

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[13] An additional analysis finds that the standard deviations for the groups' time in operation are 7.96 years and 7.99 years in the case of Pasteur's and Ruetsap's quadrants, respectively, which corroborates the findings presented here.

in Pasteur's quadrant; engineering is most represented in Edison's quadrant; while agricultural sciences are concentrated in Ruetsap's quadrant. These proportions, however, vary little, and are not any stronger than the observation that all major scientific areas are represented to the greatest extent by groups in Ruetsap's quadrant.

Having observed the characteristics of the research groups in the classification using the quadrants proposed by Stokes, our next step is to establish whether there are significant differences between these groups in terms of the characteristics of U-F interactions, especially as regards the following:

a) importance of the types of interactions established;
b) importance of the different results;
c) importance of the benefits.

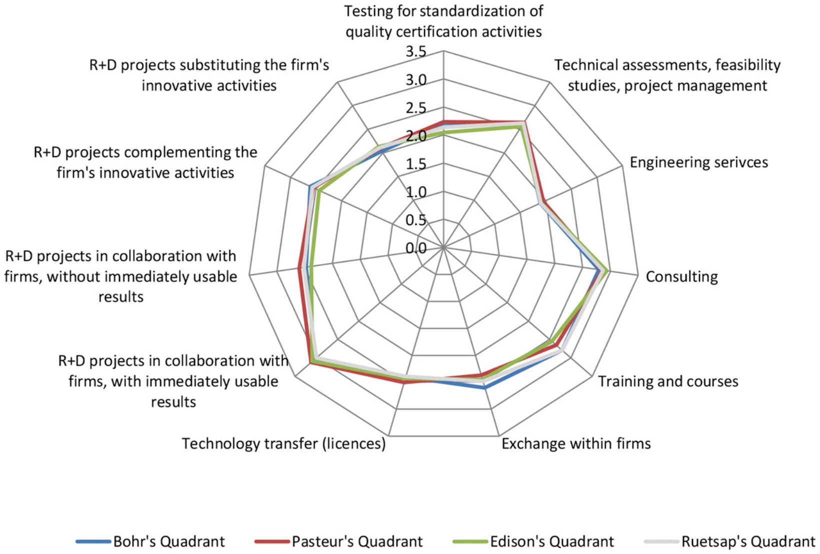
The leaders of the research groups who responded were given the option of classifying the levels of importance of their group on a scale of one to four, where:

1 = Unimportant
2 = Somewhat important
3 = Moderately important
4 = Very important

Based on this classification, we calculated the average for each cohort of research groups in the quadrants. The specific question we seek to answer is: Might the similarities in the capacity for interaction across research groups in the four quadrants – especially where the extremes, those of Pasteur and Ruetsap, are concerned – be a product of different characteristics in the types of interaction engaged in (in terms of forms of interaction, outcomes achieved, and benefits generated)? We regard this as an important question since it could lead to the identification of distinctions in the types of interactions most linked to different capacities, which would involve the understanding of the same "quantity" but different "quality" across the four quadrants. In figures 1 to 3, we proceed with the comparative analysis of these characteristics.

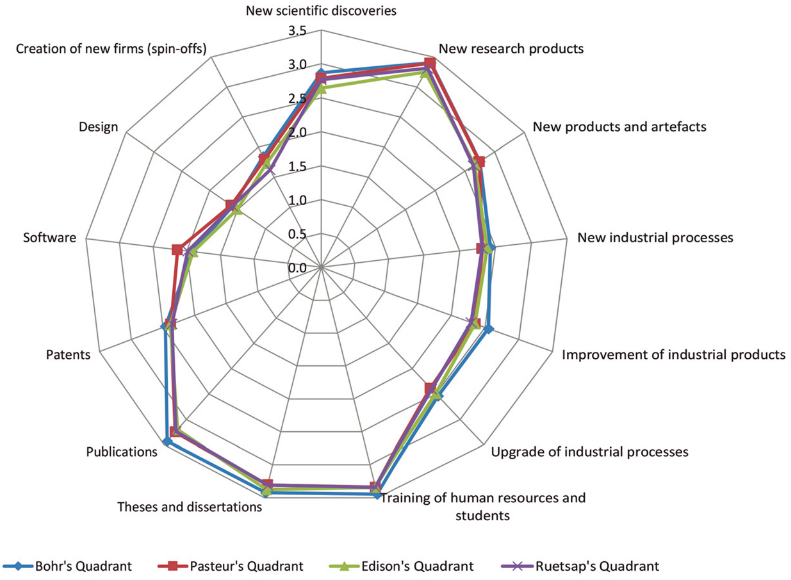
In Figure 1, we find that there are very close average values for the relationship types, with greater significance in the case of: R+D with immediate outcomes, consulting, and training, whereby the latter two forms of interaction are those that coincide with the results found by Rapini (2007a). As to the average importance of the outcomes, Figure 2 clearly illustrates the trend of higher importance attributed to those values closest to scientific outcomes such as training of human resources/students; theses and dissertations; and new research projects. Figure 2 also shows that the questions concerning technology-related outcomes, such as patents, software, design and spin-off, present the lowest average values. As regards the benefits, Figure 3 points to a lower discrepancy in the average comparisons of the values; but even then, we find somewhat higher average values for new research projects, ideas for new research projects; and exchange of knowledge, again highlighting the scientific profile to which the research groups commit in their interaction with the firms.

Figure 1
Average level of importance of forms of interaction by quadrant models



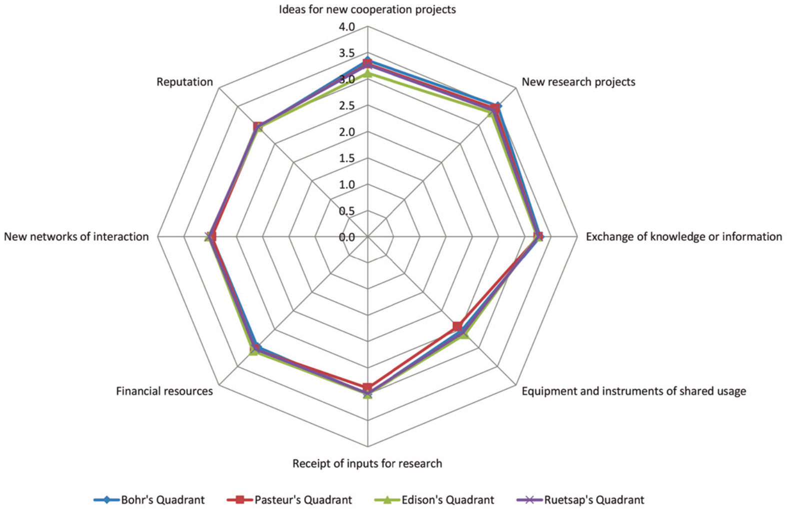
Source: BR (2006); compiled by authors.

Figure 2
Average level of importance of outcomes by quadrant models



Source: BR (2006); compiled by authors.

Figure 3
Average level of importance of benefits by quadrant models



Source: BR (2006); compiled by authors.

Beyond these observations, what needs to be highlighted in the results is that the similar capacities for interaction across research groups is mimicked by the characteristics of these interactions; indeed, we found no significant differences between the research groups from different quadrants in terms of the types, results, and benefits of interactions. Despite the different science- and technology-related skills identified in the analysis, the research groups classified do not differ in their responses to important questions about the characteristics of their interactions with firms.

One interesting result is that while it is possible to identify a cohort of groups with greater capacity in technological terms (those in Pasteur's and Edison's quadrants), their responses in relation to the characteristics of the interaction are no different from those of the groups with low scientific capacity (Bohr) or low scientific and technological capacity (Ruetsap's quadrant).

5. Final considerations

The scientist detached from mundane concerns has gradually given way to the reality of the scientific community, of intellectual workers organized at universities and firms, forming part of so-called big science. Science ceased to be seen as a process governed by mere laws of creativity – as an autonomous and independent entity of society – and came to be regarded as a product of society. Thus, advances in scientific research increasingly came to be oriented towards social and economic objectives.

Along the way, the generation of new knowledge at universities – the main locus of production of new scientific knowledge – has once again become the focus of interest of firms and the state alike. Universities thus cease to be, in the words of Mowery & Sampat (2005), "ivory towers" oriented to the pursuit of knowledge per se, and are seen as strategic assets. Thus, the main contribution of this study is to advance research in the area of the economics of science and technology, aiding understanding of the dynamics of output in this area in the case of Brazilian academia.

Our concern therefore lies in the capacities of the research groups that participated in the BR Survey to generate science and technology, and in how these capacities might relate to interactions with firms. To this end, we utilized a classification based on the quadrants proposed by Stokes (1997/2005) through the QCA statistical technique, which enables verification of conjunctural causation and makes it possible to find different patterns of behavior that lead to the same results.

By using this technique, we were able to prove that there is no well-defined pattern of scientific and technological capacity among the research groups that would lead to high levels of interaction with firms, both in terms of the total quantum of interactions and of capacity relative to the number of researchers. This non-existence of a minimum pattern of necessary conditions is an initial result, allowing us to conclude that the scientific and technological capacity of the research groups is not a necessary condition for their inclusion in U-F interactions.

The verification through QCA of better science and technology configurations for research groups serves to emphatically corroborate this result. We found, first, that the largest number of interactions occurred in Ruetsap's quadrant; and, second, that capacity relative to the number of researchers is similar between groups in Ruetsap's and Pasteur's quadrants, the two extremes of scientific and technological capability.

According to this result, unprecedented among studies of Brazilian academia, research groups with low scientific or technological capacity have engaged in more interactions in the total quantum, with close values in the analysis relative to the number of researchers, as compared to the groups with greater capacity: those in Pasteur's quadrant. This observation illustrates the need to study the quality of U-F interactions, since according to the theory we would expect the research groups in this quadrant to have less interactions with firms.**

Having tested for the possibility of distinctions in the types, outcomes, and benefits of interaction across the research groups in the different quadrants, the findings corroborate the similarity between profiles, with little to no difference in the average pattern of responses. Finally, we find insufficient difference between the major scientific areas to mark them apart.

This information attests to the already noted immaturity of Brazil's national innovation system, as expressed by Albuquerque, and the low trade-off between science and technology in this system, as argued by Ribiero *et al.* (2009), Suzigan & Albuquerque (2009), and Fernandes *et al.* (2010). One the one hand, there is a reasonable number of research groups that develop a good deal of science but little technology, whether in Bohr's quadrant or in Pasteur's. On the other hand, there is an even greater number of groups that develop neither science nor technology but do undertake U-F interactions to a greater extent than the aforementioned groups, with a relative percentage similar to that of the higher-capacity research groups.

It should be noted here that the results are a product of important but now dated research, and that the findings ought to be corroborated with more recent information, which will also serve to provide robust support for the use of these results in public policies aimed at promoting science and technology in Brazilian academia. However, when we used Stokes's proposal to find differences in capacity between research groups in Brazil, a notable gap was found between capacity and the number of interactions engaged in. Caliari *et al.* (2016) note that the greater the number of interactions with firms, the greater the capacity of the university or research institution to generate technology. We would expect this result to hold for the base of research groups observed here, with the addition of an improvement in science, thus establishing the causation necessary to promote better capacities in the Brazilian NIS.

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