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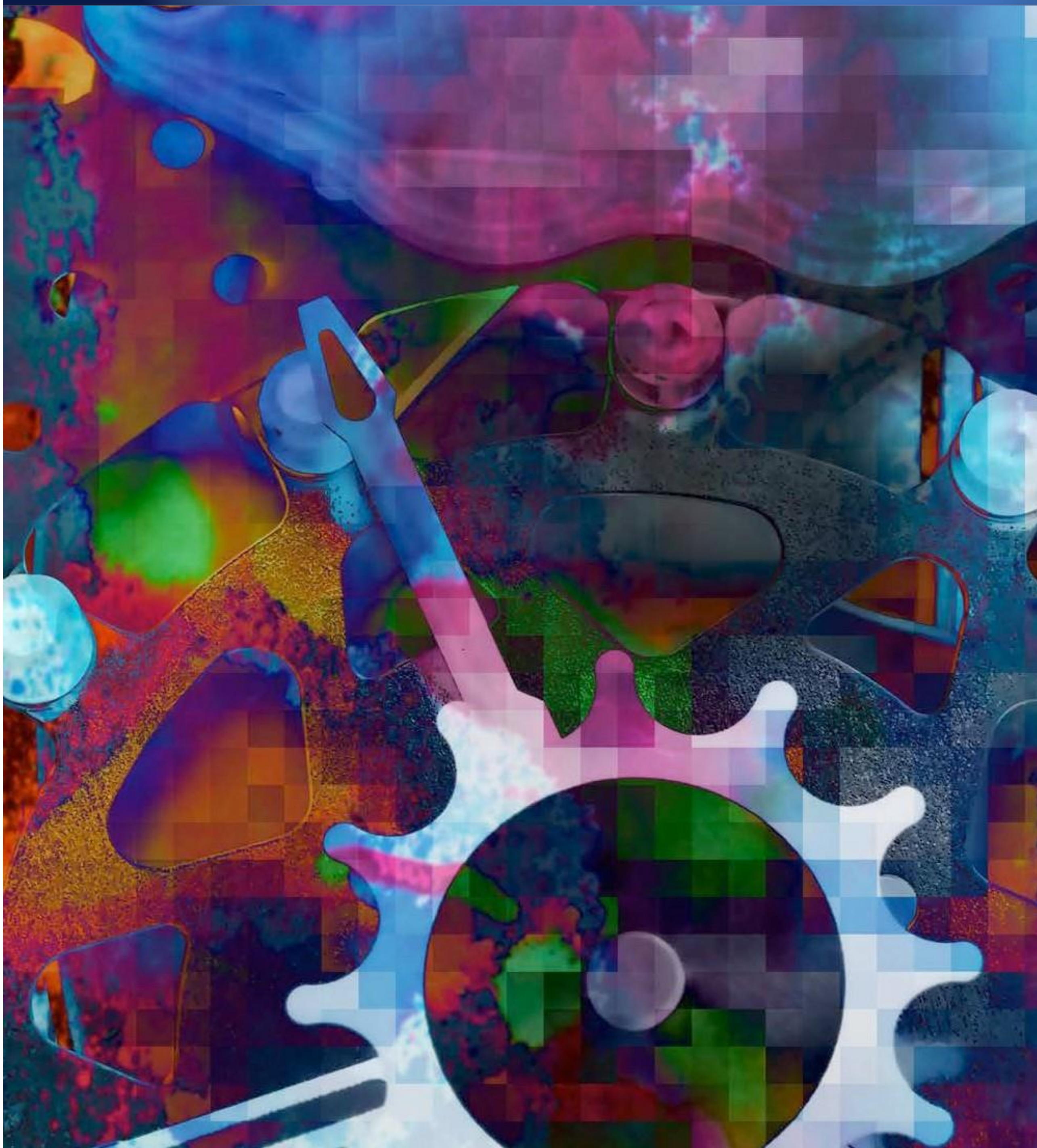

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Research infrastructures in developing countries: The Brazilian case

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Abstract

High quality research infrastructure is required to conduct S&T activities which may help to address national challenges and contribute to innovation processes. Given this, an exhaustive survey conducted by the Brazilian Institute of Applied Economic Research (*Instituto de Pesquisa Econômica Aplicada* – IPEA) was undertaken to diagnose the current research infrastructure situation in Brazil. Using this data, the present paper provides information that allows us to yield new insights based on the peculiarities of the research infrastructure in Brazil, complementing the studies already present in the literature. We propose, therefore, econometric models – Logit and Probit – to "measure" the relative modernity of the research infrastructure in the country. We test the impact of variables frequently present in innovation studies – lab size, S&T production scale and scope, longevity and interactions with other labs and firms. We found that scaling up, modernizing and interacting with other agents of the Innovation System increase the chances of a research infrastructure to be considered "advanced".

Key-words
Research infrastructure, innovation system, S&T public policy, Brazil

Introduction

Influenced by the primary studies done by F. List[i] and J. Schumpeter[ii], C. Freeman and his colleagues (Lundvall, 1992; Nelson, 1993; Kim, 1997; Freeman, 2004; Lee, 2019) have been suggesting for the past decades that public investments in science and technology (S&T) are crucial for successful economic development. Therefore, high quality research infrastructure is required to conduct S&T activities which may help to address national challenges and contribute to innovation processes.

Within the National Systems of Innovation (NSI) framework, research infrastructures are crucial *loci* for S&T advances and policy makers have been influenced by this perspective. Therefore, national efforts have been undertaken to map the country's research infrastructures such as the case of the Survey of Science and Engineering Research Facilities, conducted biennially by the U.S. National Science Foundation to collect data on the amount, construction, repair, renovation, and funding of the American research infrastructure. Other national reports have also given attention to the research infrastructure; for example, Australia (Strategic

Roadmap for Australian Research Infrastructure), Germany (Helmholtz-Roadmap for Research Infrastructures) and Finland (Finnish Research Infrastructure Survey and Roadmap).

If there are many fruitful surveys and reports on the research infrastructures of developed countries, the same cannot be said about developing countries. Even though many developing countries have their research infrastructures established, there are little national efforts to evaluate them continuously. In China, for instance, a research devoted to make a systematic evaluation of the scientific effects of its research infrastructure showed that they are relevant to the acquisition of new knowledge, and contribute to the proliferation of competitive scientific organizations and scientific talents (Qiao *et al.*, 2016).

In what regards, Brazil, which is recognized for having a non despicable scientific community and considered as an emerging power in research[iii], just very recently an exhaustive survey was undertaken to diagnose the current research infrastructure situation in the country. The survey was conducted by the Brazilian Institute of Applied Economic Research (*Instituto de Pesquisa Econômica Aplicada* – IPEA) and the data collected allows *n* possible analysis. De Negri and Squeff (2016) organized the studied which were published in 2016 and they make a comprehensive view of the features of the Brazilian research infrastructure. As a consequence we can recognize there are many contrasting labs in operation simultaneously and their size, S&T production scale and scope, longevity and interactions with other labs and firms are just some possible distinguishing characteristics we can list to perceive the existence of a research infrastructure constellation in the country.

In line with the studies organized by De Negri and Squeff (2016) and using the same database, our main objective is to provide information that allow us to yield new insights based on the peculiarities of the research infrastructure in Brazil, complementing the studies already present in the literature. We propose, therefore, econometric models – Logit and Probit – to 'measure' the relative modernity of the research infrastructure in the country. We test the impact of variables frequently present in innovation studies – lab size, S&T production scale and scope, longevity and interactions with other labs and firms.

The paper is organized as follows. In section 2, we make a concise introduction of research infrastructures and innovation in different types of NSIs. In section 3, we make a brief review of the research infrastructure in Brazil. We present the database and the econometric models in section 4. After we make a discussion the results found and finally we conclude the paper with some final remarks and policy recommendations.

2 The role of science and research infrastructures to innovation in developing countries

The concept of National Systems of Innovation (NSI) developed by some scholars (Nelson, 1993; Lundvall, 1992; Freeman, 1992) explicitly states that a firm's innovative processes result from knowledge development which is a collective action and take place both within and outside the firm. Therefore, institutional structures to support the development of technological activities are fundamental in order to consolidate a NSI.

A growing number of studies have focused on the application of the NSI framework for development issues in less developed countries (Lundvall *et al.*, 2009). These studies point the importance to "understand learning and innovation efforts in all kinds of organizations, even those far behind the technological frontier" (Cassiolato & Soares, 2015, p. 20) Moreover, the relevant knowledge could not be directly related to formal education and/or S&T systems.

There is an extensive literature that describes the roles of science to technological progress and innovation (Pavitt, 1991; Brooks, 1994; Salter & Martin, 2001) and we can summarize them as follows:

a) science is a source of new technological ideas, it enhances the knowledge stock;
b) science is a source of new research instruments and methodologies;
c) science could solve technological and innovative problems;
d) science is a source of qualified personnel;
e) science is the source of spin-offs and startups firms, for some specific scientific areas.

In developing countries science could have different roles as they face negative characteristics such as social problems and low levels of private R&D activities, some have existing scientific infrastructures – but with few areas reaching international levels, poor articulation and interaction among actors and low absorptive capacity. For those countries, science and research infrastructures may contribute significantly to the country's economic development and growth through technological and innovative efforts (Bernardes & Albuquerque, 2003; Ribeiro *et al.*¸2010). An effective research infrastructure in a developing country can produce scientific results able to play a sort of "antenna role" or a sort of "focusing device" – i.e., "an instrument to focus the direction of technological progress" (Rosenberg, 1976). In this regard, the existence of a research infrastructure signals the viable scientific and technological areas of relative success, given the domestic features and the international conjuncture. Besides, as pointed out by Foray (2010), the creation of capabilities in scientific research are frequently correlated to government action in less developed countries (LDC), since "neither multinational corporations' affiliates nor local firms have the incentives and/or capabilities to do this" (Foray, 2010, p. 102).

A second contribution of science and research infrastructures is the support of industrial development. Unlike their role played in developed countries as a source of "technological opportunities" (Klevorick *et al*., 1995) in a developing country, they contribute to identifying existing international opportunities. Among them, they could indicate the possibilities of entry into strategic industries and also could reduce the cost associated with it (Perez & Soete, 1988).

A third contribution lies in the advances in S&T towards health systems and, consequently, towards social development and economic growth (Acharya, 2007). A substantial and dynamic research infrastructure in necessary to solve national health issues. The fourth is linked to the progress in agriculture as technology should be suited to countries own environmental conditions (Mazzoleni & Nelson, 2005). The fifth contribution of science and research infrastructures is the need to adapt the technologies from developed countries to local needs (Kim, 1997; Mazzoleni & Nelson, 2005) as a lot of knowledge is necessary to select, buy, transform and use technology (Cassiolato & Soares, 2015).

3 Research infrastructures in Brazil: a brief review

Even if some public universities and research institutes were founded in the 1920s and 1930s, the Brazilian university system is relatively recent and it has been in existence for less than a century (Mello *et al*., 2009; Maculan & Mello, 2009). Compared to other Latin American countries, Brazil started relatively late on establishing universities (Suzigan & Albuquerque, 2011). While in some Latin American countries the first universities were established in the 16th century (as in Mexico and Peru) or in the 17th century (as in Bolivia), in Brazil colleges of medicine, law or engineering emerged only in the first half of the 19th century (Mello *et al.*, 2009) and the first university was established solely in 1920, in Rio de Janeiro, by the Federal Government. In 1934 the state of São Paulo created its own university (Maculan; Mello, 2009), namely São Paulo University (USP), which was Brazil' first fully-fledged university (Schwartzman, 1991).

Notwithstanding that, we can assure that the Brazilian research infrastructure was established by the 1950s with the intensification of the establishment of a great deal of public research institutes (such as the Brazilian Center for Research in Physics[iv] and the National Nuclear Energy Commission[v]) and other public universities throughout the country (Schwartzman, 1991). The period also witnessed the creation of agencies to foster the scientific research as the National Council for Scientific and Technological Development[vi] and the Coordination for the Improvement of Higher Level Personnel[vii] to build human resources' capabilities in research and to finance scientific research projects. On the same track, the Finance Agency for Studies and Projects[viii] was designed to finance S&T and innovation in firms, universities and research institutes. (Suzigan; Albuquerque, 2011). Together with the Foundations for Supporting Research[ix], they form today the core of S&T public funding agencies in the country, with 29 institutions (Table 1).

Table 1. Number of universities, public research institutes and S&T public funding agencies

Institution nature	Number
Universities[1]	197
Federally funded	63
State funded	39
Municipal funded	6
Private funded	89
Research Institutes[2]	83
Public funded	64
Private funded	19
S&T Public funding agencies	29
Federally funded (Capes, CNPq and FINEP)	3
State funded (FAPEs)[3]	26

Source: Authors' own elaboration, data sourced from ([1]) *Instituto Nacional de Estudos e Pesquisas Educadionais Anísio Teixeira* (INEP) for 2016, ([2]) *Associação Nacional de Pesquisa e Desenvolvimento das Empresas Inovadoras* (ANPEI) and ([3]) *Conselho Nacional das Fundações Estaduais de Amparo à Pesquisa* (CONFAP).

We can currently identify in Brazil 197 universities of which 55% are public institutions (Table 1). According to many studies, most of the scientific activities in the country presently are carried out by federally and state funded universities (Albuquerque *et al.*, 2002; Chiarini *et al.*, 2013). Public research institutes also play a crucial role in the production of science in the country (Chiarini *et al.*, 2013), and there are 64 of them spread throughout Brazil today. They are mainly financed by federal funds and most of them are directly linked to the Ministry of Health, Ministry of Science, Technology, Innovations and Communications and Ministry of Defense.

The establishment of the Brazilian research infrastructure was strongly influenced by the linear model of innovation (Guimarães, 2002) which, until very recently, inspired the scientific development presented in the National Plans. In 2000's, for instance, the former Brazilian Ministry of Science and Technology[x] set up a national policy based on the Sector-Specific Funds and the parliament promulgated the so-called "Innovation Law" in order to stimulate technological innovations by modernizing the regulatory environment, providing training focused on innovative activities and viewing the formulation of a S&T policy as a development strategy. Among the many sectorial funds managed by the Finance Agency for Studies and Projects, the Infrastructure Fund (CT-Infra) was designed to enable the modernization and expansion of research infrastructure in public research institutes and universities, by installing new plants and renovating labs. From 2001 (when the law was approved) to 2010, CT-Infra enabled the investment of more than USD 400 million in implementing and updating the research infrastructures in public institutions, what probably helped the Brazilian performance in producing internationally relevant scientific results (De Negri *et al.*, 2013). In fact, the number of scientific and technical papers has increased from 16.7 thousand in 2003 to 53.6 thousand in 2016[xi].

4 Methodology

4.1 Database

The database used in this paper was firstly presented by De Negri and Squeff (2016). Their study, regarding the Brazilian research infrastructure, was pioneered in the country and it was inspired by researches done for relatively more mature NSIs. The questionnaire designed by De Negri and Squeff (2016) had the following objectives:

a) Evaluate the conditions of research infrastructures in Brazil, in order to identify main bottlenecks and lacks of investment;
b) Provide detailed information for policy makers, guiding public investments;
c) Provide empirical elements for evaluating and monitoring public policies aimed at expand research infrastructures;
d) Provide information for scientific communities and profit firms in order to enable university-firm relations;
e) Provide a relevant instrument for the research institutions themselves;
f) Provide a dynamic database that allows systematic monitoring as well as reports about the evolution of the Brazilian research infrastructure.

Considering the relevant specificities of the study, the population of interest was defined as ‘research infrastructures’ based in Brazil, located in universities and/or research institutions (public and private ones), belonging to different knowledge fields (agricultural sciences, biologic sciences, earth and exact sciences, health sciences and engineering). Moreover, research infrastructures included laboratories; research ship or floating laboratories; and plants or pilot plants[xii].

After several methodological procedures[xiii] to find those infrastructures countrywide, the researchers were able to identify 4,857 infrastructures located in 185 universities and research institutes. All of them received the invitation to answer the questionnaire proposed by De Negri and Squeff (2016), however, some institutions did not respond to the questions regarding the number of labs, so database does not represent the totality of research infrastructure in Brazil[xiv].

Despite that, the response rate achieved is quite high: 36% of the research infrastructures in 70% of the institutions answered the questionnaire. Research infrastructure type and knowledge field of each one are presented in Table 2.

The research infrastructures in Brazil are predominantly laboratories (98.8%) as presented in Table 2, mainly focused in engineering (31.6%), earth and exact sciences (26.2%) and biologic sciences (22.1%). Moreover, 66.6% of research infrastructures are concentrated in only 16 universities/research institutes. We can highlight the Brazilian Agricultural Research Corporation[xv] (16.9%), University of São Paulo – USP (9.9%), Federal University of Rio de Janeiro – UFRJ (6.9%), State University of Campinas – Unicamp (5.4%), Brasilia University – UnB (4.8%), and institutions of the Brazilian Air Force[xvi] (6.8%).

Table 2. Number of respondents according to research infrastructure type and knowledge field

Research infrastructure type	Number	%
Laboratory	1,694	98.8
Research ship or floating laboratory	1	0.1
Plant or pilot plant	20	1.1
Knowledge field	**Number***	**%**
Agricultural sciences	277	13.3
Biologic sciences	459	22.1
Earth and exact sciences	545	26.2
Health sciences	143	6.9
Engineering	658	31.6

Source: Authors' own elaboration. Note: (*) The sum of knowledge field is superior than 1,715 once it was allowed to research leaders to select one or more in the questionnaire.

In the structured questionnaire prepared for the research, De Negri and Squeff (2016) asked the research leaders their perception of the relative maturity of their research infrastructures. The answers were classified as follows:

1) Advanced and compatible with the best research infrastructures worldwide;
2) Advanced for Brazilian standards, however not compatible with the best research infrastructures worldwide;
3) Adequate and compatible with other domestic research infrastructures;
4) Insufficient in relation to other research infrastructures in Brazil;
5) Not able to evaluate.

For statistical purposes and simplicity, we used a more synthetic procedure, establishing only three possible classifications:

a) Advanced research infrastructure: infrastructures classified as 1 and 2;
b) Sufficient research infrastructure: infrastructures classified as 3;
c) Insufficient research infrastructure: infrastructures classified as 4.

The final database (after treatments for inconsistencies) is composed of 1,715 research infrastructures, distributed as follows: advanced research infrastructure (622), sufficient research infrastructure (722) and insufficient research infrastructure (371).

4.2 The econometric models

We compare the categories presented in the previous sections separately, in order to generate two econometric models in which the dependent variable is a binary answer (0 or 1), as presented in Table 3.

Table 3. Econometric models proposed

Econometric Models	Categories	Binary answer
Model 1	Insufficient research infrastructure	0
	Advanced research infrastructure	1
Model 2	Insufficient research infrastructure	0
	Sufficient research infrastructure	1

Source: Authors' own elaboration.

Table 4. Explanatory variables

Explanatory Variables	Description	Theoretical intent
Monetary value attributed[xvii]	It is considered four categories: a) up to US$ 230.000 (base category); b) from US$ 231.000 to US$ 462.000; c) from US$ 463.000 to US$ 4,63 million; d) above US$ 4,63 million.	Economies of scale
Multidisciplinarity	Dummy variable: a) multidisciplinary scientific infrastructures (1); b) otherwise (0).	Economies of scope
Modernization period	Variable that indicates when the last modernization was carried out in the scientific infrastructure. Categories are: a) up to 1 year (base category); b) from 1 to 5 years; c) from 5 to 10 years; d) from 10 to 15 years; e) there was none.	Technological vanguard
Operation time (lifespan)	Infrastructures' operation period.	Importance of the longevity of the research (proxy for research maturity)
Cooperation with Brazilian Research institutions	Importance attributed (low, medium or high importance) for the cooperation with other Brazilian research institutions. The base category is 'low importance'.	Interaction with S&T peers
Cooperation with foreign research institutions	Importance attributed (low, medium or high importance) for the cooperation with foreign research institutions. The base category is 'low importance'.	
Cooperation with domestic firms	Importance attributed (low, medium or high importance) for the cooperation with domestic firms. The base category is 'low importance'.	University-industry interactions
Cooperation with foreign firms	Importance attributed (low, medium or high importance) for the cooperation with foreign industrial firms. The base category is 'low importance'.	
Geographic Regions	Dummy variable for Brazilian regions (Southeast, South, Northeast, North and Midwest). The base category is 'Southeast region'.	Control group
Science Index	Factor Analysis for the number of research articles, book chapters and published books by researchers.	Scientific results' importance
Technology Index	Factor Analysis for the number of patent applications (national and international).	Technological results' importance

Source: Authors' own elaboration.

The control group is the "insufficient research infrastructure" category (dummy = 0). We use Logit and Probit econometric techniques to generate results for both models. We also perform

Shapiro-Wilk and Shapiro-Francia Normality tests on the dependent variable. This procedure specifies that such variables follow a normal distribution, which indicates the use of a Probit model. Despite that, many researchers opt to use a Logit model since the interpretation of the coefficients is easier. In addition, by the Central Limit Theorem, the logistic distribution approaches the normal distribution. Therefore, to avoid any criticism, we opt to use both techniques. Algebraic specifications follow Wooldridge (2002). The considered explanatory variables are as specified in Table 4. We present in Table 5 and Table 6 descriptive statistics about all variables used in the econometric models.

Table 5. Descriptive statistics – dummy variables

Variables	Number	Percentage
Research infrastructure		
Advanced	622	36.3%
Sufficient	722	42.1%
Insufficient	371	21.6%
Monetary value attributed		
up to USD 230.000	1,023	59.7%
from USD 231.000 to USD 462.000	294	17.2%
from USD 463.000 to USD 4,63 million	344	20.1%
above USD 4,63 million	53	3.1%
Multidisciplinarity	285	16.6%
Modernization period		
up to 1 year	560	32.7%
from 1 to 5 years	673	39.2%
from 5 to 10 years	190	11.1%
from 10 to 15 years	106	6.2%
there was none	186	10.8%
Cooperation with domestic research institutions		
Low importance attribution	444	25.9%
Medium importance attribution	523	30.5%
High importance attribution	748	43.6%
Cooperation with foreign research institutions		
Low importance attribution	964	56.2%
Medium importance attribution	335	19.5%
High importance attribution	416	24.3%
Cooperation with domestic firms		
Low importance attribution	1,055	61.5%
Medium importance attribution	309	18.0%
High importance attribution	351	20.5%
Cooperation with foreign firms		
Low importance attribution	1,589	92.7%
Medium importance attribution	76	4.4%
High importance attribution	50	2.9%
Geographic regions		
Southeast	977	57.0%
South	411	24.0%
Northeast	164	9.6%
North	52	3.0%
Midwest	111	6.5%

Source: Authors' own elaboration.

Some initial observations may be extracted from the information presented in the previous Tables. A large number of research infrastructures are classified as "advanced" or "sufficient" and have been recently modernized (up to 5 years). However, they have limited scale and limited muldisciplinary use. They are mainly located in the Southeast and South regions of the country, confirming other studies that show the regional concentration of science production in Brazil (Chiarini *et al.*, 2013).

Furthermore, research infrastructures are more able to establish cooperation with domestic peers than with foreign ones, showing that Brazilian research infrastructures are not yet internationalized. In addition, we can notice that cooperation with (domestic or foreign) firms is not seen as of high-importance, corroborating the current literature on the topic (Silva Neto *et al.*, 2013). The observation of S&T indexes, presented in Table 6, corroborate the previous finding, since the average value for “science” is higher than for “technology”.

Table 6. Descriptive statistics – continuous and discrete variables

Variables	Number	Average	S-D	Lower limit	Upper limit
Operation time (lifespan)	1,715	14.65	12.79	0	104
Science Index	1,715	0.0051	0.98	-0.60	14.33
Technology Index	1,715	0.0036	0.80	-0.19	18.56

Source: Authors’ own elaboration.

5 Results and Discussions

We present in Table 7 (in the next page) results from our econometric models. We opt in presenting also odds-ratio from the Logit model since it is of practical understanding. Research leaders’ perception on research infrastructure’s relative technical capacity is considered as a proxy for scientific capability. For this, we consider two axioms: first, no one has more information about research infrastructures than the research leaders; second, research leaders have complete information about their knowledge field, therefore they are able to compare their reality with all existing research labs in the world.

Models are adjusted rapidly by the likelihood method (five interactions), and chi-square value presents statistical significance for both regressions. Still, results achieved by both Logit and Probit methods were congruent (both for significance and coefficients’ signs).

5.1 Economies of scale and scope

Economies of scale and scope are documented in the literature as important features of industrial capitalism (Chandler, 1994), being the cost-diminishing by increase of production (scale) or by producing goods with complementary productive process (scope). Alternatively, one may highlight the inverse of cost (productivity) as the focus of analysis from scale and scope economies; in this view, a firm may produce more increasing its factory size as well as increasing the number of complementarity products produced at same factory.

Some studies consider these features in measuring scale and scope at research (Vonortas *et al.*, 2011; Vonortas, 2009), educational (Johnes & Johnes, 2016; Koshal & Koshal, 1999; Olivares & Wetzel, 2011), and scientific levels (Cohen, 1981; 1991; Cockburn & Henderson, 2001; Hernandez-Villafuerte *et al*, 2017, Kannebley *et al*, 2018). Results are not conclusive and points out to a mix of distinct results. Some point to linear positive economies of scale (Cohen, 1981; Cockburn & Henderson, 2001) and/or economies of scope (Kannebley *et al*, 2018), while others present this positivity until some specific size. An inverse U-shaped relation may be seen in the results presented by Vonortas *et al.* (2011) and some empirical studies demonstrated by Hernandez-Villafuerte *et al* (2017) for funded biomedical and health research, or a well-marked maxima of publication rates (Qurashi, 1984), which may point the risks of both “too large” and “too small” research projects. Some studies show that large-scale research infrastructures are more able to involve many scientists and technicians increasing the possibilities of cooperation (Lozano *et al*., 2013; Del Bo *et al.*, 2016; D’Ippolito & Rüling, 2019), generating economic spillovers, particularly through learning (Foray, 2004). Despite the inconclusiveness of the topic, public policies have been created to strengthen research infrastructures and incentivize their growth (EC, 2010; OECD, 2010).

Table 7. Econometric models

Variables	Model 1 Comparison with advanced research infrastructures			Model 2 Comparison with sufficient research infrastructures		
	Logit	***Odds-Ratio Logit***	**Probit**	**Logit**	***Odds-Ratio Logit***	**Probit**
Monetary value attributed to the infrastructure						
from USD 231.000 to USD 462.000	1.27*	3.56*	0.72*	0.67*	1.95*	0.40*
from USD 463.000 to USD 4,63 million	2.44*	11.51*	1.38*	1.10*	3.00*	0.64*
above USD 4,63 million	empty	empty	empty	empty	Empty	empty
Multidisciplinarity	0.40**	1.50**	0.21***	0.02	1.02	0.00
Modernization period						
from 1 to 5 years	-0.19	0.83	-0.13	-0.16	0.85	-0.10
from 5 to 10 years	-1.05*	0.35*	-0.63*	-0.79*	0.45*	-0.48
from 10 to 15 years	-1.90*	0.15*	-1.11*	-1.25*	0.29*	-0.77*
there was none	-1.92*	0.15*	-1.12*	-1.30*	0.27*	-0.80*
Operation time (lifespan)	0.02*	1.02*	0.01**	0.02**	1.02**	0.01*
Cooperation with domestic research institutions						
Medium importance attribution	0.69*	1.99*	0.40*	0.192	1.211	0.118
High importance attribution	0.80*	2.23*	0.47*	0.114	1.121	0.075
Cooperation with foreign research institutions						
Medium importance attribution	0.84*	2.31*	0.49*	0.285	1.330	0.167
High importance attribution	1.35*	3.85*	0.76*	-0.227	0.796	-0.135
Cooperation with domestic firms						
Medium importance attribution	0.59*	1.81*	0.33**	0.35***	1.41***	0.21***
High importance attribution	0.87*	2.39*	0.49*	0.40***	1.48***	0.23***
Cooperation with foreign firms						
Medium importance attribution	0.43	1.63	0.20	0.25	1.28	0.12
High importance attribution	0.11	1.12	0.08	-0.32	0.73	-0.17
Geographic regions						
South	-1.16*	0.31*	-0.67*	-0.49*	0.61*	-0.29*
Northeast	-0.82*	0.44*	-0.46*	-0.05	0.945	-0.01
North	-1.66*	0.19*	-1.00*	-0.19	0.83	-0.12
Midwest	-1.65*	0.19*	-0.93	-0.25	0.78	-0.14
Science Index	0.17	1.18	0.10	0.21	1.23	0.12
Technology Index	-0.06	0.95	-0.03	-0.18	0.84	-0.10
Constant	-0.75*	0.47*	-0.43*	0.71*	2.03*	0.43*
Observations	1715			1715		
LR (qui-square)	491.17		490.55	140.24		140.94
Prob > *qui-square*	0.00		0.00	0.00		0.00
Pseudo-R^2	0.387		0.386	0.101		0.101

Source: Authors’ own elaboration. Notes: (*, **, ***): significant at 1%, 5% and 10% respectively. Control Groups: ‘insufficient research infrastructure’; monetary value attributed: ‘up to US$ 230.000’; modernization period: ‘up to 1 year’; geographic regions: ‘southeast’; cooperation: ‘low importance’.

Given the above, we try to capture the importance of economies of scale for research infrastructures in Brazil. The results we find are slightly different from those already presented in the literature once we do not measure outputs but the relative perception of research leaders when comparing their research infrastructures with others domestically and internationally. In doing so, they consider the relative quality in producing scientific results for a given infrastructure.

Having that in mind, our econometric estimations point out to the importance of scale for research infrastructures in Brazil. First of all, we found there is no singular research infrastructure whose monetary value is above USD 4,63 million classified as “insufficient”; they are either classified as “advanced” (82% of time) or “sufficient” (18% of time).

Research infrastructures whose monetary value attributed is above USD 463 thousand are 11.5 times more likely to be classified as ‘advanced’ than infrastructures bellow USD 231 thousand. According to research leader’s perception, the relevance of scale is monotone-increasing. When analyzing the sufficient research infrastructures (Model 2, Table 7), coefficients’ signals are the same as Model 1, however with smaller magnitudes. Scale is closely related to quality perception, so the question about the catching up of research infrastructures pass on an improvement on machinery, equipment and physical installations.

In what regards the scope of research infrastructures, the results follow pretty much the same pattern as their scale, however in smaller magnitude and only for advanced research infrastructures. Multidisciplinary research infrastructures have 49,8% more chances to be classified as “advanced” in comparison with “insufficient” ones. The same is not valid for “sufficient” versus “insufficient” comparisons, as can be seen by the presence of coefficients econometrically insignificant.

When putting in parallel research infrastructures’ scale and scope, one can note a greater importance to the first. As a consequence, increments on research infrastructure’s scale are an important improvement observed by research leaders. Therefore, as almost 60% of research infrastructures are monetarily worth less than USD 230 thousand, an improvement on monetary values for scientific breakthrough is raised. Besides, U-shaped relation would not be identified from our database since the percentage of advanced research infrastructure is monotonically increasing for their attributed monetary value (42.1%, 77.8%, 92.5% and 100% respectively). That means that research infrastructures seem to be in the crescent side of the curve.

5.2 Technological progress and research maturity

Scientific developments are frequently supported and increased by technological improvements (Kline; Rosenberg, 1986). Nowadays, with the rapid advancements of science and the fast-technological obsolescence, the importance of research infrastructure modernization is even more urgent. This is well-captured by our econometric models. Coefficients are significant for both models (from five years of modernization on), even with greater magnitude for “advanced versus insufficient” research infrastructure comparison. Two observations are interesting and may be considered for both models regarding technological obsolescence.

First of all, research infrastructures modernized more than ten years before the Survey are classified as bad as infrastructure with no modernization, since coefficients are statistically the same. In a few words, those research infrastructures are roughly 6.8 times less likely to be “advanced” and roughly 3.8 times less likely to be “sufficient”, as one can expect. Secondly, the Survey respondents consider there is no difference between “up to 1 year” and “from 1 to 5 years” classifications, which indicate a “satisfaction” degree until the upper limit (five years). After that, research infrastructure seems to be impaired.

The previous findings bring out relevant insights for those who subsidize research institutions: constant modifications have to be made in their labs, at least in the medium term, so research infrastructures can sustain their quality standards. Since the majority of scientific infrastructures are maintained by federal government in Brazil (De Negri; Squeff, 2016), the problem is even more pressing with economic authority and the constant budget reductions in the last years (Carvalho, 2018), especially for S&T.

Additionally, we tested our model for the influence of research maturity, which can be explained by the research infrastructure lifespan. The variable is also able to identify a learning curve (Ritter; Schooler, 2002). Despite statistical significance, the impact of the operation lifespan is very small in both models, which leads us to suggest that opportunities can be achieved by new labs. This result is in line with the one found by Cohen (1991), who proposes that there is no indication of timing entry barriers.

5.3 Cooperation

Cooperation and interactions are relevant for a NSI (Freeman, 1992), as already presented previously. Some studies highlight the importance of universities in generating technologies, both inside and outside their boundaries (Cohen *et al.*, 2002; Wright, Birley & Mosey, 2004). Besides that, specific attention is given to university-firm interactions (Sjoo & Hellstrom, 2019; Klevorick *et al.*, 1995; Mansfield, 1991), and the Brazilian case is not an exception (Caliari & Rapini, 2017; Caliari, Santos, & Mendes, 2016; Rapini, 2007; Suzigan & Albuquerque, 2011).

In this paper, we tested the cooperation of research infrastructure with other labs and their interactions with firms, both classified as domestic and foreign. Results show different perspectives from research leaders in accessing "advanced" or "sufficient" classifications. For research infrastructure classified as "sufficient", cooperation with domestic firms presents statistical significance while with foreign firms it does not. It is worth noting as well that there is no difference among medium and high levels of importance of cooperation with domestic firms. Furthermore, the coefficient of cooperation is smaller than the coefficients of other explanatory variables.

We also find evidences that structural changes on research infrastructure may be achieved with cooperation. For example, a research lab which gave high importance to interactions with other labs – either domestic or foreign – and to domestic firms are approximately 8.5 times more likely to be "advanced" than research infrastructure which gave low importance to these interactions.

Cooperation with foreign firms was not markedly important to differentiate infrastructure technical capacity. The high importance given to cooperate with foreign firms is underscored by only 31 advanced scientific labs (4,9%) while other types of cooperation were indicated as important by 57.9% (domestic institutions), 33.8% (foreign institutions) and 32.3% (domestic firms) of those scientific infrastructures.

5.4 Geographic regions

Regions are important for knowledge creation and learning, therefore regions' research structure may generate feedbacks on the regions' economic system (Florida, 1995). This process is related to Myrdal's circular cumulative causation (Myrdal, 1960) where inequalities are reinforced by the system; in this view, strong economies are associated with strong regional innovation systems in a self-reinforcement process (Cooke, 2001; Santos & Caliari, 2012).

Taking this into account, a correlation among economy size and research structure is expected, which means relatively more advanced research infrastructure are located in more advanced economic regions. Table 8 presents information to sustain these argument, repeating econometric results (column 2) besides economic and S&T regional concentrations (columns 3 and 4). Econometric coefficients are from odds-ratio results; all of them are statistically significant.

Table 8. Comparative Information under Regional Classification

Geographic Region	Probability of being advanced	% of research infrastructures	% of Brazilian GDP
Southeast	1.00	57.0	54.0
South	0.31	24.0	16.8
Northeast	0.44	9.6	14.2
North	0.19	3.0	5.3
Midwest	0.19	6.5	9.7

Source: Authors' own elaboration.

As it can be seen in Table 8, the percentage of research structures are correlated with the size of each regions' economies (GDP), however we can notice that the former is more concentrated than the latter (Hirschman-Herfindahl index for research infrastructure is 3,968.4, while for GDP is 3,522.1). This means a high degree of reinforcement of S&T effects on the economic structure, which is congruent with Cavalcante (2011). We can also find in the literature econometric evidences that prove that the uneven distribution of S&T resources in the country is mainly explained by the imbalanced regional research infrastructure (Fagundes et al, 2005). Moreover, other studies show that the research infrastructure asymmetry within regions reflect their S&T outputs (Chiarini *et al*., 2013; Sidone *et al*, 2016).

Our finding goes against the policy implemented by federal governments in the 2000s and middle 2010s for the decentralization of higher education (BRASIL, 2015; Pires & Silva, 2009). Our analysis show that despite the implementation of policies to decentralize the research infrastructure with the inauguration of new research institutes in the Northeast – such as the Center for Strategic of the Northeast[xviii] and the Semi Arid National Institute[xix] – and the establishment of new public universities in the Northeast and Midwest – such as the Federal University of Recôncavo da Bahia – UFRB, and the Federal University of Grande Dourados – UFGD –, research infrastructures are still highly concentrated. Those policies had positive immigration effects of students for less-developed regions (Barufi, 2014), however, relevant research infrastructures are still more concentrated than the provision of higher education. Then, circular cumulative causation effects are established, which the decrease in retention of students in those less-developed areas.

This inequality reinforcement feedback can be seen in the econometric analysis: research infrastructures located in the Southeast Region are approximately 5.2 times more likely to be "advanced" than research infrastructures in the North and Midwest Regions, for example. Northeast Region seems to be an outlier. Despite its low percentage of research infrastructure (9.6% of total research infrastructure from Brazil is located there), 44% of them seem to be comparable with the ones from the Southeast Region, which is a higher number even compared to the South Region (31%). Here there may be a virtuous result from regional policies, since economic growth in the Northeast was higher than Brazil's average in the last years, but more studies need to be done to deepen this finding.

5.5 Scientific and Technological Outputs

Scientific and technological results (publications and patents) are possible outputs from research infrastructures. Additionally, one can remind that there are intangible benefits, spillovers and externalities of the investment in research infrastructure (Del Bo *et al.*¸2016) that was not captured in our models

Our findings reveal that neither scientific nor technological results are statistically significant on research leader's perception on their research infrastructure. Notwithstanding this result, we believe it may be related with existing correlations among both labs' economic scale and scientific/technological results, as we can depict from Table 9.

Table 9. Comparative Information about scientific and technological outputs

Monetary value attributed	Average Scientific Output	Average Technological Output
Up to USD 231.000	-0.130	-0.076
From USD 232.000 to US$ 463.000	0.158	-0.006
From USD 463.000 to US$ 4,63 million	0.228	0.199
Above USD 4,63 million	0.334	0.118

Source: Authors' own elaboration.

There is a monotonically and mathematically crescent relationship between the research infrastructure scale and average scientific outputs, however the same conclusion is not valid for scale and technological output. As a consequence, we made particular tests to verify the former association. We do not find multicollinearity when testing the dependent variables by VIF command[xx], but it is not a definite conclusion since research infrastructure scale is defined by a Likert scale type. Consequently, we processed alternative regressions without infrastructure scale and considering only for the Logit model (Table 10, annex).

When using these alternative regressions, we identify two relevant findings: i) scientific outputs are statistically significant to explain both 'advanced' and 'sufficient' research infrastructure, as suggested before; and ii) all remaining explanatory variables present the same results (considering sign, magnitude and statistical significance of coefficients), which indicate the validity of scale and science' correlations, with robust results for further variables. Better statistical adjustments came from main models so we are already considering the best econometric fit.

Conclusions

In Brazil, research infrastructures started to be built about 50 to 60 years ago. Today, the country has a considerable developed research infrastructure constituted, in the majority, by public labs within public universities and public research institutes. So, this structure is due mainly by efforts from federal government in last decades.

Considering that and the importance of infrastructure for S&T advancements, an extensive work was conducted in order to quantify S&T infrastructures (De Negri & Squeff, 2016). We used this database and we identified the determinants of the relevance of research infrastructure, categorized as "advanced", "sufficient" or "insufficient". Our econometric results corroborate theoretical and empirical findings, with distinct impact from variables, allowing to define hierarchy.

Firstly, being bigger (infrastructure scale) and having state-of-art technology are remarkably important to reach "advanced" status. Considering the previous finding, increasing labs' scale seems to be a more urgent need than their modernization: roughly 72% of scientific infrastructures were modernized in the last 5 years, but only 23% of them are monetarily valued above US$ 463 thousand. However, relatively modern infrastructure does not maintain its modernity if no further investments is done.

We also found evidences that interactions with other agents of the Brazilian Innovation System have impacts on the research infrastructure. Researchers who perceive as “high important” the interactions with other labs – both domestic and foreign ones – and also with Brazilian firms are approximately 8.5 times more likely to be relatively more “advanced” than those researchers who consider these interactions of “low importance”. Despite that, the interactions are focused mainly in peer-cooperation (research institutions) and domestic firms, which corroborates the low cooperation profile of Brazilian institutions. On this way, many discussions regarding current improvements for Brazilian S&T capabilities focus on the need of establish more cooperative arrangements, mainly with foreign institutions and firms.

Scope, scientific output and operation lifespan also present statistical significance, but with lower magnitude. Additionally, results present inequality reinforcement feedback from regional analysis, which need to be tackled if policy makers are trying to sought a strategy focused on scientific regional inequality reduction.

As an important appointment from this study, we highlight the susceptibility of Brazilian infrastructure to public budgetary fluctuations. Therefore, our findings are likely to be relevant for research infrastructures’ managers who depend mainly on public resources, which have been reduced drastically in the last few years in Brazil. It is urgent the search for new sources of income. One possible way to overcome this reduction, in order to prevent activities interruption, is by approximating the public labs to private companies and/or foreign institutions. An efficient approximation strategy must pursue the increase scale besides sustaining modernity standards of the labs.

Our models suggest that centers of excellence tend to reach better this suggestion, since they are more attractive for private intentions. Moreover, the importance of cooperation points out the dual relevance of this strategy.

Nonetheless, it has to stay clear that private funding is mainly focused on applied technological matters, so this suggestion would be applicable just in specific fields and for specific cases. Thus, even if a cooperative approach with private institutions is achieved by some research infrastructures, it is true that some researches that do not present clear market potential should continue to depend on public entities for their continuity and growth. We understand, therefore, that policy makers should think in stable public policies on this matter whose importance for both economic and social developments are undeniable.

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Annex

Table 10. Multicollinearity test for dependent variables

Variables	VIF	1/VIF
Monetary value attributed to the infrastructure		
from USD 231.000 to USD 462.000	1.37	0.731
from USD 463.000 to USD 4,63 million	1.68	0.596
above USD 4,63 million	1.89	0.529
Multidisciplinarity	1.30	0.768
Modernization period		
from 1 to 5 years	1.89	0.529
from 5 to 10 years	1.31	0.764
from 10 to 15 years	1.23	0.812
there was none	1.27	0.789
Operating time (lifespan)	2.76	0.362
Cooperation with domesticresearch institutions		
Medium importance attribution	2.10	0.475
High importance attribution	3.65	0.274
Cooperation with foreign research institutions		
Medium importance attribution	1.66	0.602
High importance attribution	2.34	0.428
Cooperation with domestic firms		
Medium importance attribution	1.38	0.723
High importance attribution	1.77	0.565
Cooperation with foreign firms		
Medium importance attribution	1.23	0.813
High importance attribution	1.20	0.832
Geographic regions		
South	1.30	0.767
Northeast	1.11	0.898
North	1.04	0.960
Midwest	1.10	0.907
Science Index	1.13	0.888
Technology Index	1.08	0.930

Source: Authors' own elaboration.

Table 11. Alternative Econometric Model

Variables	Model 1 Odds-Ratio Logit	Model 2 Odds-Ratio Logit
Multidisciplinarity	1.590**	1.095
Modernization period		
from 1 to 5 years	0.787	0.830
from 5 to 10 years	0267*	0.434*
from 10 to 15 years	0.151*	0.285*
there was none	0.138*	0.254*
Operation time (lifespan)	1.031*	1.021*
Cooperation with domestic research institutions		
Medium importance attribution	1.759*	1.242
High importance attribution	2.164*	1.227
Cooperation with foreign research institutions		
Medium importance attribution	2.157*	1.361
High importance attribution	3.732*	0.756
Cooperation with domestic firms		
Medium importance attribution	2.161*	1.515**
High importance attribution	3.731*	1.731**
Cooperation with foreign firms		
Medium importance attribution	1.508	1.592
High importance attribution	0.793	0.698
Geographic regions		
South	0.265*	0.605*
Northeast	0.416*	0.944
North	0.137*	0.885
Midwest	0.178*	0.791
Science Index	1.352*	1.257**
Technology Index	1.013	0.866
Constant	0.822	2.247*
Observations	949	1083
LR (qui-square)	418.74	117.42
Prob > qui-square	0.00	0.00
Pseudo-R^2	0.319	0.084

Source: Authors' own elaboration.

[i] "National System of Political Economy".
[ii] "Theory of Economic Development" and "Capitalism, Socialism, and Democracy".
[iii] https://www.economist.com/the-americas/2011/01/06/go-south-young-scientist
[iv] *Centro Brasileiro de Pesquisas Físicas* – CBPF.
[v] *Comissão Nacional de Energia Nuclear* – CNEN.
[vi] *Conselho Nacional de Desenvolvimento Científico e Tecnológico* – CNPq.
[vii] *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – Capes.
[viii] *Financiadora de Estudos e Projetos* – FINEP.
[ix] *Fundações de Amparo à Pesquisa* – FAPEs
[x] *Ministério da Ciência e Tecnologia* – MCT and today *Ministério da Ciência, Tecnologia, Inovações e Comunicações* – MCTIC.
[xi] Data sourced from the World Bank. Scientific and technical journal articles refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.
[xii] For simplicity, "research infrastructure" is exchangebely called "lab" throughout this paper and both have the same meaning for us.
[xiii] Those methodological procedures were described by De Negri and Squeff (2016).
[xiv] As argued by De Negri and Squeff (2016), it not seems a limitation since Crow and Bozzeman (1998) were able to identify approximately 15,000 infrastructures in United States.
[xv] *Empresa Brasileira de Pesquisa Agropecuária* – Embrapa.
[xvi] Aeronautics Institute of Technology (*Instituto Tecnológico de* Aeronáutica – ITA), Aeronautics and Space Institute (*Instituto de Aeronáutica e Espaço* – IAE) and Advanced Studies Institute (*Instituto de Estudos Avançados* – IEAv).
[xvii] The original values were quoted in Brazilian Reais (BRL). We convert to US Dollars (USD) considering the average exchange rate of 2013 (period when the research was conducted).
[xviii] *Centro de Tecnologias Estratégicas do Nordeste* – CETENE.
[xix] *Instituto Nacional do Semiárido* – INSA.
[xx] Results for multicollinearity test are presented in Table 10 (annex).