Efficiency of research and development efforts in Brazil

Eficiência dos esforços de pesquisa e desenvolvimento no Brasil

LUIZ RICARDO CAVALCANTE
Consultoria legislativa do Senado Federal / Professor do mestrado em administração pública do Instituto rasileiro de Ensino, Desenvolvimento e Pesquisa (IDP).
Brasília – DF – Brasil
orcid.org/0000-0003-1894-7238
luiz.ricardo.teixeira.cavalcante@gmail.com

Abstract

This paper presents an analysis of the aggregate efficiency of the Brazilian research and development (R&D) efforts and compares it with those of a number of selected countries. R&D efficiency is measured as the ratio of selected R&D outputs to inputs. R&D efforts are measured in terms of: *i)* expenditures; and *ii)* number of researchers. R&D outputs are measured in terms of *i)* scientific and technical publications; and *ii)* patent applications. Results indicate that besides investing less than other countries of reference in R&D, Brazil is also less efficient in converting these investments into publications and patents. Brazil is relatively more efficient in publications than in patent applications. Although the determinants of R&D aggregate efficiency have not been investigated, results suggest that it is affected by economies of scale and that countries with lower levels of expenditures can increase their efficiency when they specialize in specific R&D fields.

Keywords: R&D efficiency; R&D expenditures; innovation policies; Brazil.

Resumo

Neste trabalho analisa-se a eficiência agregada dos esforços de P&D no Brasil, comparando-o com um conjunto de países selecionados. A eficiência é calculada como a razão entre indicadores de resultado e de esforço de P&D. Os esforços são medidos com base: *i)* nos dispêndios; e *ii)* no número de pesquisadores. Os resultados são aferidos com base *i)* em publicações técnicas e científicas; e *ii)* patentes aplicadas. Os resultados indicam que além de investir menos em P&D do que outros países de referência, o Brasil é também menos eficiente em converter esses esforços em publicações e em patentes. O Brasil é relativamente mais eficiente para produzir publicações do que para gerar patentes. Embora os determinantes da eficiência agregada dos esforços de P&D não tenha sido objeto de análise neste trabalho, os resultados sugerem sua associação com economias de escala e que países com menores níveis de investimentos podem aumentar sua eficiência ao se especializem em áreas específicas de pesquisa.

Palavras-chave: eficiência de R&D; dispêndios de R&D; políticas de inovação; Brasil.

http://dx.doi.org/10.51861/ded.dmvdo.037
Recebido em: 13 de maio de 2021. Aprovado em: 11 de novembro de 2021.

1 – Introduction

There is a widespread consensus that science, technology and innovation (ST&I) play a central role in economic development (SCHUMPETER, 1942). Freeman (2007) argues that innovation represents a "crucial source of effective competition, of economic development and the transformation of society". Based on that perception, several countries have adopted innovation policies (LUNDVALL; BORRÁS, 2005) and fixed targets to increase their R&D investments as a way of achieving higher levels of development (CARVALHO, 2018). The Lisbon strategy and the Europe 2020 strategy, for example, stated that 3% of the European Union's gross domestic product (GDP) should be invested in R&D. The same target had been established in the case of the United States by the Obama administration (MERVIS, 2021). Developing countries have also established targets for their R&D expenditures or for their business enterprise R&D expenditures, as was the case of Brazil in the 2010s (BRASIL, 2011).

However, the impacts of those policies on the development indicators fall short of expectations. As stressed by Carvalho (2018, p. 373), "the popularity of the R&D intensity indicator remains high despite the complete lack of effectiveness of R&D policy based on R&D intensity targets". The lack of effectiveness is usually credited to the difficulties of accomplishing the established R&D expenditure targets themselves (CARVALHO, 2018) and to the limitations of the so-called "linear model of innovation" (VIOTTI, 2008). This model assumes, in its stylized description, that innovation results from sequential steps from basic research to applied research and then to development, production and marketing. In the case of Brazil, the pulverization of resources has been considered an additional factor that restricts the impacts of the R&D expenditures (CAVALCANTE, 2018). However, the efficiency of R&D efforts (i.e., the capacity of converting efforts such as investments into scientific publications or patents) has been the subject of a reduced number of analyses and has had little impact on ST&I policies. A few papers mentioned in section 2 of this paper do deal with this subject (LEE; PARK, 2005; SHARMA; THOMAS, 2008; THOMAS; SHARMA; JAIN, 2011; AKSNES et al., 2017), but none of them discusses the Brazilian case. Furthermore, those papers use different measures of R&D efficiency.

Brazil has been adopting ST&I policies for some decades and managed to increase its R&D expenditures, although still lagging behind developed countries. In 2017, R&D expenditures in Brazil as a percentage of GDP reached 1.26%. Although higher than the figures in other Latin-American economies such as Argentina and Mexico and in the so-called BRICS (except for China), R&D expenditures in Brazil are much smaller than in developed economies. Even when compared with countries like Australia and Canada, which are relevant commodity exporters like Brazil (and, as such, less likely to present higher levels of R&D investment given their sectoral structure), R&D investments in Brazil are reduced. China is advancing very rapidly towards developed countries' indicators of R&D expenditures. In 2017, that country invested more in R&D as a percentage of GDP than Australia and Canada. These figures reinforce the perception that, given its relatively low levels of R&D expenditures, Brazil must not only raise them, but also increase the efficiency of expenditures in order to convert local efforts into scientific and technological results.

This paper analyzes the aggregate efficiency of the Brazilian R&D efforts and compares it with those of a number of selected countries. To that end the study: *i*) defines a set of efficiency indicators based on the ratios of R&D output measures to input measures; and *ii*) tabulates these efficiency indicators for Brazil and a set of selected countries (BRICS, Argentina, Mexico and some developed countries of reference). Besides this introduction, this paper is structured in four additional sections. Section 2 presents a brief review of previous works that have dealt with R&D efficiency (or 'R&D productivity', in some cases) at the national level. Section 3 describes the methodological procedures adopted to estimate R&D efficiency indicators. Results are discussed in section 4 and in section 5 presents the paper's main conclusions.

2 – Bibliographic review

Discussions about R&D efficiency at the national (aggregate) level are relatively rare in the literature. In fact, as stressed in the introduction of this paper, most analyses focus on the inputs or the outputs themselves, but not on the association between these two aspects, and analyses of R&D efficiency usually focus on firms (in order to support strategic decisions on investments, for example) (HANEL, 2000; TSAI, 2003). However, we identified some earlier papers that did measure R&D efficiency at the national level, as discussed in the remainder of this section.

Lee and Park (2005) measured what they called 'R&D productivity' (defined as the ratio of output to input) at the national level for 27 countries in the late 1990s. Those authors considered the following set of inputs and outputs:

Box 1: variables used by Lee and Park (2005)

Type	Variable	Description
Input	R&D expenditure	Average R&D expenditure of a country for the period 1994-1998.
	Researchers	Average number of researchers of a country for the period 1994-1998
Output	TBR	Technology balance of receipts in 1999
	Articles	Number of scientific and technical journal articles in 1999
	Patents	Number of triadic patent families in 1999

Source: Lee and Park (2005).

The authors initially measured the 'total factor productivity (TFP)' for each output. As a result, every single output is associated with the combination of the two inputs indicated in box 1. In practice, the authors assumed that *i*) R&D expenditure is analogous to 'capital'; and *ii*) the number of researchers is analogous to 'labor' in the traditional TFP models. In their words, "inputs and outputs of R&D employed in the previous studies were not so different from each other. Inputs include the number of researchers or the number of R&D personnel as labor, and R&D expenditure or R&D intensity as capital" (LEE; PARK, 2005, p. 209). As they use data envelopment analysis (DEA) to measure R&D productivity in such a way that "multiple outputs of outputs" can be taken into consideration, in practice, Lee and Park (2005, p. 207) define several productivity measures "by combining single input with all outputs and single output with all inputs in order to measure specialized R&D efficiency". As the authors acknowledge that R&D inputs are not converted into outputs instantly, they assume a three-to-five-year lag between R&D inputs and R&D outputs.

Lee and Park's work (2005) provides several elements for the analysis performed in the remainder of this paper: *i*) they define a general measure of efficiency (as the ratio of outputs to inputs); *ii*) they select the main input and output variables; and *iii*) they consider a lag between inputs and outputs. However, the authors do not consider the nature of the analyzed inputs even though some of them are more focused on the scientific or 'academic' production, whereas others focus on technological production. Furthermore, the assumption that R&D expenditures would be a kind of production factor related to capital might be problematic, because sometimes these expenditures are simply directed at hiring researchers. In fact, a significant part of the R&D expenditures measured according to the Frascati Manual (OECD, 2002) is directed at researchers' remuneration.

Sharma and Thomas (2008) also used DEA to analyze the R&D efficiency of a group of 22 countries with R&D expenditures above 0.75% of GDP. They reaffirm the possibility of measuring R&D efficiency as the ratio of R&D outputs to inputs. In particular, they use the ratio of patents to gross domestic expenditure on research and development (GERD) as their measure of R&D efficiency. Sharma and Thomas (2008) recognize that publications could also be used as an indicator of outputs but argue that *i*) they may suffer from language bias; and *ii*) most publications have multiple authors (sometimes from different countries) and, as a result, it is not easy to determine their respective contributions. As a result, their R&D efficiency indicator relies only on the ratio of patents to GERD. The authors resume their results as follows: "in a nutshell, the study indicates that efficient utilization of R&D resources across nations has the potential to radically change the growth scenario in many parts of the world" (SHARMA; THOMAS, 2008, p. 499).

Leydesdorff and Wagner (2009) discuss the contribution of indicators at the macro-level from a scientometric perspective and relate percentages of world share of publications to government expenditure on academic research. That allows them to estimate a 'price per paper' in different countries using data on expenditures from the 'Main S&T Indicators' of the Organization for Economic Co-operation and Development (OECD) and from the science citation index (SCI) available at the

Web-of-Science of the Institute of Scientific Information (of Thomson Reuters). As for the input measure, Leydesdorff and Wagner (2009, p. 355) argue that GERD is composed of three main components: *i*) business expenditure on R&D (BERD); *ii*) higher education expenditure on R&D (HERD); and *iii*) government intramural expenditure on R&D (GOVERD) and that "HERD cannot be considered as a sufficient indicator of input to academic research because in some nations (e.g., China, the Russian Federation) the Academy is a major contributor to scientific publishing." As a result, they use both HERD and (HERD + GOVERD) as indicators for academic publishing. As for the output indicators, Leydesdorff and Wagner (2009, p. 355) argue that "the best practice in scientometrics [is] to include only citable issues, that is, articles, reviews, and letters." That explains their choices of scientific efficiency indicator components and how they avoid the problems associated to combining articles and patents in a single output indicator.

Thomas, Sharma and Jain (2011) calculate R&D efficiency as the ratio of patents granted and scientific publications to R&D expenditures for the states of the USA and for the BRICS countries. In practice, they add up the data on patents and publications for the year 2008 and divide the result by the R&D expenditure for the year 2005. Their sources are USPTO, UNESCO and the ISI Web of Science. In short, Thomas, Sharma and Jain (2011, p. 9) conclude that "all the BRICS nations with the exception of Russia, show robust increases in R&D efficiency (between 2004 and 2008), in sharp contrast to the declining performance of the states of the USA". However, by simply combining data on patents and publications, Thomas, Sharma and Jain (2011) tend to obtain some "blurred" results, as these kinds of output have different features (technological and scientific, respectively). Besides, the scale of patents and publications sometimes is really different as is the case with Brazil, where publications may reach tens of thousands and yet there are only a few hundred patents per year. That may explain why Brazil showed 'robust increases' in R&D efficiency between 2004 and 2008, when the number of publications grew very fast, but the numbers of patents, though erratic, remained at a low level (CAVALCANTE, 2018).

Aksnes et al. (2017) investigate the methodological problems in measuring research productivity at the national level. Initially, they estimate the 'productivity of national R&D-systems' as the number of publications in a given year (2012) per gross domestic expenditure on R&D in current million PPP USD in the same year ("the most simple and rough measure of the scientific productivity of nations"). However, Aksnes et al. (2017) also argue that *i*) scientific publishing is only one result of R&D; *ii*) this type of output is not equally important for the different R&D performing sectors; and *iii*) a way to overcome that problem is to exclude business enterprise GERD and to limit the analysis to the higher education and government sectors (similarly to Leydesdorff and Wagner, 2009). Aksnes et al. (2017) also express concern about the measurement of scientific output, especially regarding internationally co-authored publications and the way of crediting them across countries. That leads those authors to use a fractional counting scheme. They point to the lag between inputs and outputs and to other ways of measuring R&D inputs (using data on human resources).

The literature review discussed so far shows that publications and patents are the output indicators most commonly used to measure R&D efficiency. Some of the reservations regarding publications as an indicator of scientific production of a given country have already been mentioned above. There is also some misgiving about using patents as an indicator of technological production. First, patents are a measure of invention, but not necessarily of innovation. In fact, on several occasions, although patents have represented some new product or process, they have had no economic applicability. When institutions realize that their performance might be measured on the basis of patent applications (e.g., universities or research centers), there might be some incentive for them to apply for patents with little or no economic impact. Griliches (1990) highlights that "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in terms of quality".

At the country level, the number of patent applications and concessions is strongly affected by sectoral composition. For example, countries with a higher presence of pharmaceutical firms tend to have more patents than countries with a higher presence of traditional sectors. However, Lotti and Schivardi (2005) have shown that large and persistent cross-country differences cannot be explained by the sectoral composition alone, as patent propensity differs substantially even within sectors. In other words, the number of patents is affected by the sectoral structure, but even within similar sectors there might be cross-country differences. It is also affected by research productivity, appropriability propensity and strategic propensity factors (Danguy et al., 2009). The results obtained by Johansson et al. (2015) summarize the debate: "controlling for research and development, industry composition, and institutional setting, the paper shows that systematic differences in patent intensity exist between the studied countries, such that almost all industries are affected by country-specific conditions, suggesting that the countries' innovation systems differ in efficiency".

This paper does not investigate the reasons that may explain cross-country differences in R&D efficiency, it just analyzes the aggregate efficiency of the Brazilian R&D efforts and compares it with those of a number of selected countries. That explains why this review focusses on papers that define R&D efficiency indicators and that register some cross-country comparisons. However, a natural follow-up of the analysis of the performance is the analysis of its determinants, and some papers did focus on that subject. Chen, Yang and Hu (2011), for example, investigated how the innovation environment, especially in the national innovation system, affects these output-oriented R&D efficiency indicators and concluded that R&D intensity, intellectual property rights protection, knowledge stock, and human capital accumulation all have significantly positive effects on efficiency indexes.

3 – Methodological procedures

As discussed in the previous section, the efficiency of R&D efforts can be generically defined as their capacity for generating scientific or technological results. Basically, the measures correspond to the ratio of a given output indicator to a given input indicator. An average lag between inputs and outputs is usually defined before computing the efficiencies. In this paper, in particular, R&D efforts were measured in terms of *i*) R&D expenditures; and *ii*) number of researchers, whereas R&D outputs were measured in terms of *i*) scientific and technical publications, and *ii*) patent applications. Most indicators are available for a large number of countries. Here, however, the analysis has been limited to a number of selected countries to which Brazil is recurrently compared when innovation policies are discussed. These countries are:

- BRICS (Brazil, Russian Federation, India, China and South Africa), which are large developing economies.
- Mexico and Argentina, which are two large Latin-American economies that may be used as a reference for comparisons with Brazil.
- The United States, as a large economy and a leading country in ST&I.
- Canada and Australia, as large and developed economies that rely on commodity exports.
- South Korea, a country that has managed to catch up over the last decades and that is sometimes used as a benchmark for the Brazilian economy with regard to ST&I policies.
- Germany, as a leading economy of the European Union.

Of course, any selection of this kind is, to some extent, *ad hoc*. However, there is no intention to explore the reasons that may explain the behavior of the R&D efficiency indicators (which would require a larger database), a limited number of countries seems more appropriate to illustrate the proposed indicators. As a result, other leading countries in ST&I which are not usually compared with Brazil (Japan, for example) have not been included in the sample. At any rate, further research may consider using a larger number of countries in order to perform econometric analyses of the performance of the proposed indicators.

The remainder of this section is structured as follows: subsections 3.1 and 3.2 detail the procedures to obtain the R&D input and output data for the selected countries. Subsection 3.3 describes the way the indicators were combined in order to generate the efficiency indicators.

3.1 R&D efforts

As mentioned above, in this paper, R&D efforts are measured in terms of *i*) R&D expenditures; and *ii*) number of researchers. In practice, we considered R&D input indicators related both to the gross domestic expenditure on R&D and to the full-time equivalent (FTE) of R&D personnel. In each case, we split the data into a 'paper oriented' part, basically not related to business enterprises and in practice mainly related to the government and to universities and public research centers, and a 'patent oriented' part, basically related to business enterprises.

3.1.1 R&D expenditures

R&D expenditures are by far the most widely used ST&I indicator for international comparisons. This paper considered data regarding *i*) gross domestic expenditure on R&D (GERD) not financed by business enterprises (government, higher education, private non-profit, rest of the world and non-specified sources) of country *i* in year *t* ($GERD\text{-}n\text{-}BE_{i,t}$) and *ii*) GERD financed by business enterprises of country *i* in year *t* ($GERD\text{-}BE_{i,t}$). These data are produced at the country level usually on the basis of the OECD standards such as the Frascati Manual (OECD, 2002) and the Oslo Manual (OECD, 2005). The main international institutions that collect and standardize these data are indicated below:

- United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute for Statistics (UIS);[1]
- Eurostat;[2] and
- OECD Main Science and Technology Indicators (MSTI) database.[3]

We used UIS because it is not limited to the OECD or to the European Union countries. The data are available in a number of ways (local currency or USD, current or constant prices and as a percentage of GDP, for example). To enable international comparisons to be made and because the last available year is not always the same for all countries, GERD was expressed in USD PPP in constant prices (in the case of the UIS, the reference year is 2005).

GERD is segmented according to the source of funding as follows: *i*) financed by government; *ii*) financed by higher education; *iii*) financed by private non-profit; *iv*) financed by rest of the world; *v*) financed by a non-specified source; and *vi*) financed by business enterprise. The same segmentation is also available for performed GERD (for example, when the expenditures are financed by the government, but performed by business enterprises). In this paper, we simply considered *GERD-n-BE* and *GERD-BE* as proxies for 'paper-oriented' and 'patent-oriented' efforts. In other words, we assumed the expenditures mainly financed by the government (*GERD-n-BE*) focus on academic production, whereas expenditures financed by business enterprises (*GERD-BE*) focus on technological production.

1 http://data.uis.unesco.org.

2 https://ec.europa.eu/eurostat/data/database.

3 http://data.uis.unesco.org/.

3.1.2 Number of researchers

Another measure of R&D efforts used in this paper is the full-time equivalent (FTE) number of researchers. These data are available at the country level in UIS. Again, we used the total FTE of R&D personnel not employed by business enterprises (government, higher education, private non-profit and non-specified sectors) of country i in year t ($RDP\text{-}n\text{-}BE_{i,t}$) and the total FTE of R&D personnel employed by business enterprises of country i in year t ($RDP\text{-}BE_{i,t}$). The idea is again to split the efforts into two groups, the first related to academic production and the other to technological production.

3.2 R&D outputs

R&D outputs were measured in terms of *i*) scientific and technical publications; and *ii*) patent applications.

3.2.1 Scientific and technical publications

Data regarding scientific and technical production were extracted from the SCImago Journal & Country Rank website, which is "a publicly available portal that includes the journals and country scientific indicators developed from the information contained in the Scopus® database (Elsevier B.V.)".[4] In particular, we considered the number of citable documents (exclusively articles, reviews and conference papers) of country i in year t, ($CD_{i,t}$).

3.2.2 Patent applications

Data regarding patent applications were extracted from the World Intellectual Property Organization (WIPO)-administered Patent Cooperation Treaty (PCT) applications originating in country i in year t, ($PA_{i,t}$).[5] The PCT system seeks patent protection for an invention simultaneously in a number of countries by filing a single international patent application, and the origin of PCT applications is defined by the residence of the first-named applicant.

Of course, several caveats must be considered when dealing with these data as a proxy for technological output. As shown is section 2, patents are a measure of invention, but not necessarily of innovation. Besides, high-tech industries tend to patent more than low-tech industries; as a result, the productive structure in each country influences the number of patents. In spite of limitations like those, several papers (including many of the ones mentioned in section 2) use the number of patent applications or patent concessions as a proxy for the technological performance of countries and firms.

As for the choice of PCT applications (and not other sources or concessions instead of applications), we decided to work with a more widespread measure for

4 https://www.scimagojr.com/aboutus.php.

5 http://www.wipo.int/ipstats/.

international comparisons. Furthermore, as the number of applications is higher than the number of concessions, to avoid very small numbers (which could hinder international comparisons of backward countries), we opted for applications instead.

3.3 Efficiency indicators

As shown in the box below, the indicators described in sections 3.1 and 3.2 are combined in such a way that *i*) efforts not financed or employed by business enterprises are associated with citable documents (generating the 'scientific efficiency' indicators); whereas *ii*) efforts financed or employed by business enterprises are associated with patent applications (generating the 'technological efficiency' indicators).

Box 2: R&D efficiency indicators

		R&D expenditures	**Number of researchers**
R&D outputs	**Scientific and technical publications**	Scientific efficiency of R&D expenditures (*$SEE_{i,t}$*): $SEE_{i,t} = CD_{i,t+d} / GERD\text{-}n\text{-}BE_{i,t-3}$	Scientific efficiency of R&D personnel (*$SEP_{i,t}$*): $SEP_{i,t} = CD_{i,t+d} / RDP\text{-}n\text{-}BE_{i,t-3}$
	Patent applications	Technological efficiency of R&D expenditures (*$TEE_{i,t}$*): $TEE_{i,t} = PA_{i,t+d} / GERD\text{-}BE_{i,t-3}$	Technological efficiency of R&D personnel (*$TEP_{i,t}$*): $TEP_{i,t} = PA_{i,t+d} / RDP\text{-}BE_{i,t-3}$

Source: elaborated by the author.

The definitions used in this paper are similar to the ones used by Thomas, Sharma and Jain (2011), but instead of working with a general output measure (scientific publications + patents) and a general measure of input (GERD), we consider specific scientific and technical efficiencies. Aksnes et al. (2017) also use indicators similar to the scientific efficiency of R&D expenditures, but do not use personnel or patent data, as we did in this paper. As a result, the way the efficiency indicators were defined in this paper is both consistent with the previous literature and innovative. In line with the literature reviewed in section 2, we used an average lag of three years between efforts and outputs, so that results refer to 2018 and efforts refer to 2015.

The four R&D efficiency indicators indicated in box 1 are self-explanatory on the basis of the variables used to compute them. The scientific efficiency of R&D expenditures ($SEE_{i,t}$) was measured as the number of citable documents in 2018 per USD million in expenditures not financed by the business enterprise sector in 2015 and the scientific efficiency of R&D personnel ($SEP_{i,t}$) was measured as the number of citable documents in 2018 per FTE researcher not employed by business enterprises in 2015. As for the technological efficiency of R&D expenditures ($TEE_{i,t}$), we considered the number of PCT applications in 2018 per USD billion in expenditures financed by the business enterprise sector in 2015 and for the technological efficiency of R&D personnel ($TEP_{i,t}$) we considered the PCT applications in 2018 per thousand R&D personnel employed by business enterprises in 2015. In each case, we set the order of magnitude to obtain more easily comparable absolute numbers.

Although the efficiency of R&D expenditures could be compared to a kind of 'capital productivity', whereas the efficiency of R&D personnel would be more like a kind of 'labor productivity', such associations must be used with caution, especially in the first case. In fact, as shown in section 2, R&D expenditures might be significantly directed to researchers' remuneration and not to research infrastructure alone.

Of course, other indicators and sources such as OECD data on R&D expenditures or domestic patents applications could have been used. In this paper, however, the criteria for source and indicator selection were aimed at: *i*) maximizing the number of countries available in the data sources; and *ii*) focusing on the most common indicators used for international comparisons (for example, in the case of PCT applications). At any rate, other indicators or sources, although eventually leading to different absolute numbers, do not significantly change the country efficiency rankings presented in the remainder of this article.

4 – Results

The input data for the calculation of the R&D efficiency indicators calculated according to the definitions presented in the previous section for the selected countries are shown in table 1:

As the table shows, *GERD-n-BE* (in practice, expenditures mainly financed by the government) in 2015 ranges from USD 3.6 billion, in Argentina, to USD 116.2 billion, in the United States, whereas *GERD-BE* ranges from USD 1.0 billion to USD 296.8 billion in the same countries. These figures show that scales strongly vary inside this relatively small sample of countries. Similar figures are observed for the remaining variables in table 1. Of course, these variables are usually weighted by GDP or population, for example, but at any rate there are minimum scales required to leverage R&D efficiency.

Table 1: input data for the calculation of the R&D efficiency indicators

	GERD-n-BE 2015 (USD 1,000)	GERD-BE 2015 (USD 1,000)	Researchers-n-BE 2015	Researchers-BE 2015	Citable documents 2018	PCT applications by filing date, 2018
Brazil	19,722,452	16,496,119	141,704	50,486	74,195	615
China	79,269,949	262,294,263	604,414	1,014,614	569,227	53,357
Russian Federation	9,820,402	14,252,374	240,576	208,604	95,359	1,034
India	31,031,320	15,436,477	208,148	74,846	152,110	2,007
South Africa	2,786,312	2,078,261	21,533	4,627	21,843	275
Mexico	5,843,163	1,335,327	24,175	10,107	22,515	273
Argentina	3,569,432	1,034,977	48,284	4,722	13,185	42
United States of America	116,189,654	296,846,583	388,457	981,000	570,104	56,260
Canada	10,908,824	12,436,155	67,375	95,577	95,047	2,415
Australia	7,839,504	8,994,722	n,d,	33,016	89,153	1,826
Republic of Korea	15,668,512	54,053,452	72,311	284,136	79,646	16,918
Germany	27,844,379	60,983,900	157,159	230,823	158,437	19,740

Sources: UNESCo/UIS, SCImago Journal & Country Rank and WIPO. Elaborated by the author.

Following the literature mentioned in section 2, we considered a three-year average lag between inputs and outputs. As a result, data regarding the citable documents refer to 2018, whereas data regarding expenditures refer to 2015. The scientific efficiency of R&D expenditures, for example, measures the number of papers generated as a result of USD 1.0 million R&D investments mainly directed to scientific research three years before. Of course, the lag assumed between efforts and results varies from research to research and the choice here is somewhat arbitrary, albeit even a choice for no lag at all would be arbitrary. It was decided to follow the literature and a kind of average expectation and set the lag at three years. At any rate, other choices would not have strongly affected the main results obtained in this paper.

Data shown in table 1 were used to calculate the R&D efficiency indicators defined in box 2. Results are registered in table 2. As shown in the header, values were sometimes expressed in USD millions, USD billions or 1,000 researchers, in order to obtain more manipulable indicators.

Table 2: R&D efficiency indicators by selected countries

	$SEE_{i,t}$ Citable documents (2018) per USD million in expenditures not financed by the business enterprise sector (2015)	$SEP_{i,t}$ Citable documents (2018) per R&D personnel not employed by business enterprises (2015)	$TEE_{i,t}$ PCT applications (2018) per USD billion in expenditures financed by the business enterprise sector (2015)	$TEP_{i,t}$ PCT applications (2018) per thousand R&D personnel employed by business enterprises (2015)
Brazil	3.76	0.52	37.28	12.18
China	7.18	0.94	203.42	52.59
Russian Federation	9.71	0.40	72.55	4.96
India	4.90	0.73	130.02	26.82
South Africa	7.84	1.01	132.32	59.44
Mexico	3.85	0.93	204.44	27.01
Argentina	3.69	0.27	40.58	8.89
United States of America	4.91	1.47	189.53	57.35
Canada	8.71	1.41	194.19	25.27
Australia	11.37	0.00	203.01	55.31
Republic of Korea	5.08	1.10	312.99	59.54
Germany	5.69	1.01	323.69	85.52

Source: elaborated by the author.

As shown in table 2, Brazil produced 3.76 citable documents per USD million in R&D expenditures mainly financed by the government (i.e., disregarding the expenditures financed by the business enterprise sector). As a result, the scientific efficiency of R&D expenditures in Brazil is about one third of that of Australia, about 75% of that of the United States and 50% of that of China. Brazil is very close to the other Latin-American countries (Mexico and Argentina). The relatively low efficiency of the United States seems puzzling, even when compared with other non-English-speaking countries like Russia and China, especially taking into account that several papers refer to a sort of 'language bias' of scientific publications in favor of English-speaking countries. At any rate, the results indicate that the scientific efficiency of R&D expenditures in Brazil is low. It might be associated, for example, with a reduced R&D infrastructure (i.e., some sort of capital stock which can increase scientific production even in the absence of large recent investments) and with increasing returns on scale (i.e., countries that invest more in R&D tend to present higher levels of efficiency). Those hypotheses, however, are not tested in this brief analysis, as it deals only with a reduced sample of countries.

Data regarding the scientific efficiency of R&D personnel (also shown in table 2) basically indicate the number of citable documents produced by researchers employed mainly by the government (it includes, for example, researchers at universities and research centers, but excludes researchers working in business enterprises). Again, Brazil ranks among the less efficient countries in the sample. Although more efficient than Argentina and Russia, Brazil's scientific efficiency of R&D personnel is about half of several other countries' (including China and Mexico) and a little more than one third of that of the United States and Canada. Of course, efficiency (or 'productivity') is related not only to the R&D infrastructure, but also to the level of investments. Researchers working in modern labs equipped with modern equipment obviously tend to publish more than researchers working in precarious conditions. Furthermore, the pulverization of resources might contribute to lowering the scientific efficiency of Brazil's R&D personnel. As shown by Cavalcante (2018, p. 381), "bureaucrats responsible for the allocation of resources to financing innovation activities have more incentives to pulverize the resources over a large number of small projects than to concentrate them in a smaller, but more coherent number of projects". The loss of focus and the small scale of the projects tend to reduce the efficiency. Although the present article sets out to identify the problem and not its causes, the role of all these factors must be investigated in order to tackle it.

Similar exercises have been conducted for the technological efficiency of R&D expenditures and of R&D personnel. In both cases, as shown in table 2, the distance between Brazil and the leading countries is greater than in the case of scientific efficiency. Regarding the technological efficiency of R&D expenditures, the study considered the number of PCT applications in 2018 per USD billion in R&D expenditures financed by the business enterprise sector in 2015. Basically, it was assumed that R&D expenditures financed by the business enterprise sector are more focused on innovations at the firm level. The technological efficiency of R&D personnel corresponds to the number of PCT applications in 2018 per thousand R&D personnel employed by business enterprises in 2015.

This study estimated that in Brazil there were approximately 37 patent applications per USD billion in R&D expenditures financed by the business enterprise sector. This figure is about 12% of that of Germany or South Korea, the leading

countries in the sample. Countries like Mexico, China, Australia and Canada presented technological efficiencies of R&D expenditures more than five times the indicator estimated for Brazil.

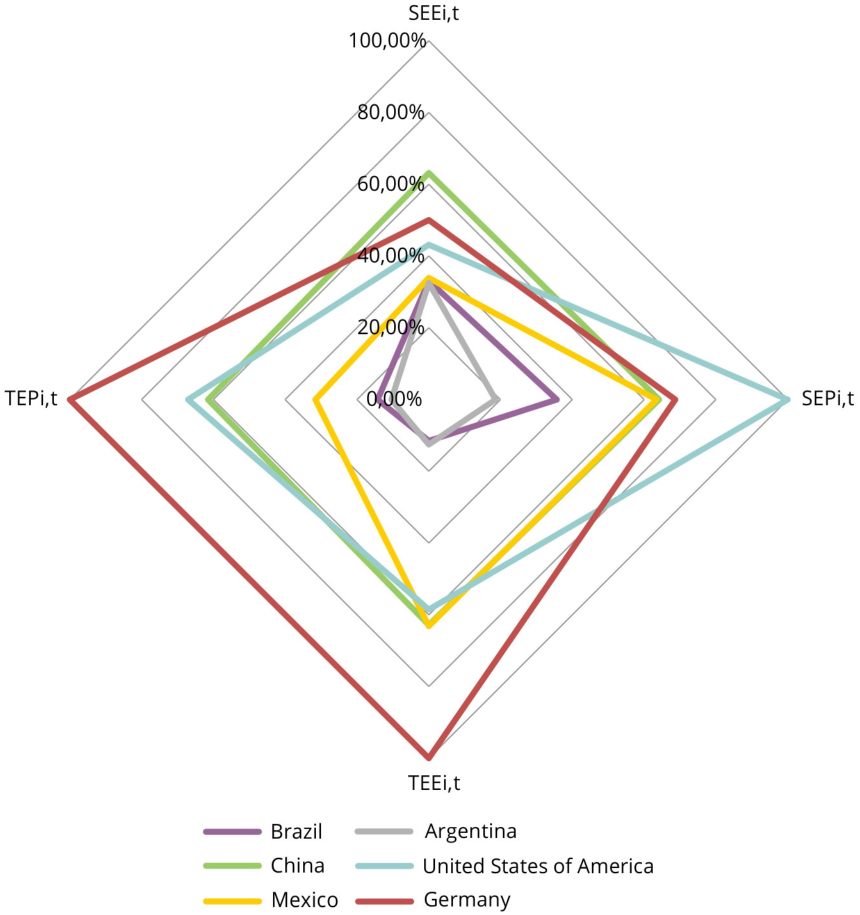
As for the technological efficiency of R&D personnel, in Brazil every thousand researchers employed by business enterprises in 2015 is associated with about 12 patents in 2018. Although more efficient than Argentina (9) and Russia (5), Brazil lags behind the other countries in the sample. The technological efficiency of Brazil's R&D personnel is about half of that of Mexico, India and Canada, a quarter of that of several other countries and less than 15% of that of Germany. No country in the sample presented a value below that of Brazil.

Of course, the reservations regarding patents mentioned above are also applicable to the technological efficiency data reported in this section. Nevertheless, the results reported in table 2 are not only consistent with previous analyses of Brazil's poor patenting performance (see, for example, Albuquerque, 2001), but also indicate that there is a long road ahead if the country wishes to improve the technological efficiency of its R&D efforts.

Graph 1 highlights the particularly uncomfortable position of Brazil when the four indicators are normalized (i.e., maximum values are set to 100%). It shows the results for Brazil and five selected countries, but the inclusion of additional ones does not change the overall results of the analysis.

As shown in the graph, only Argentina has an overall position comparable to that of Brazil. Mexico presented much better results in both technological dimensions as well as in the scientific efficiency of R&D personnel. China and the developed countries performed much better than Brazil in all four dimensions.

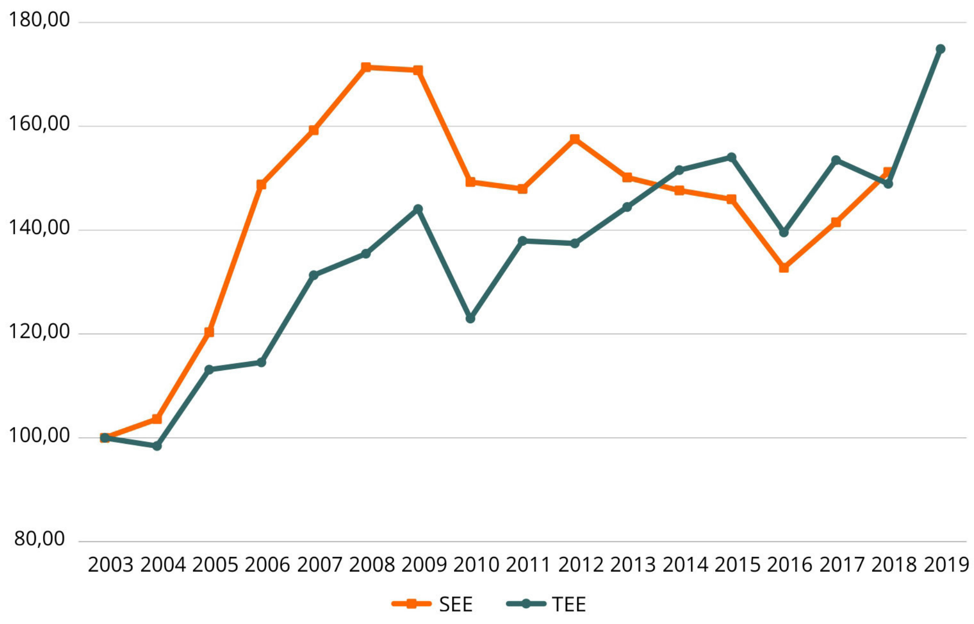
Graph 1: normalized R&D efficiency indicators, selected countries



Source: elaborated by the author.

So far, the analysis in this article has focused on cross-country comparisons at a given moment. No time-series have been estimated for the countries in the sample, but specifically in the case of Brazil, we used data available in the web page of the Ministry of Science, Technology, and Innovation (MCTI is the acronym in Portuguese) in order to compute the scientific and the technological efficiency of R&D expenditures over the last few years. The sources are not necessarily the same as those used previously (for example, for patents, the data refer to USPTO applications), but the results are reasonably comparable with the ones reported in table 2. Again, we considered a three-year average lag between inputs and outputs. Graph 2 shows the normalized results (2003 = 100.00) for the period between 2003 and 2019.

Graph 2: scientific (SEE) and technological (TEE) efficiency of R&D expenditures, Brazil, 2003-2019 (2003 = 100.00)



Source: MCTI. Elaborated by the author.

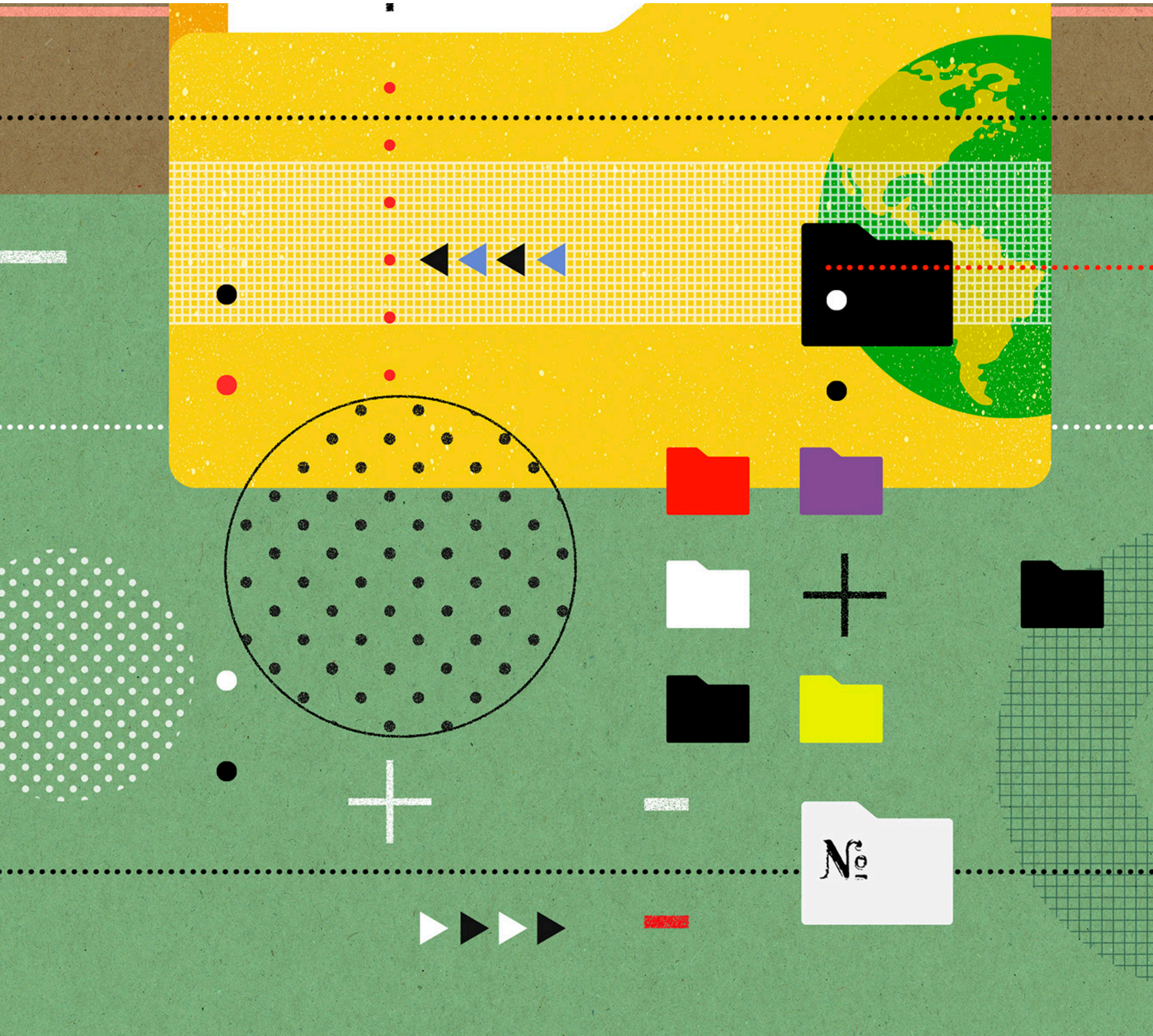
The graph shows that between 2003 and the late 2010s, both the scientific and the technological efficiencies in Brazil grew steadily, reaching values around 70% higher, in the first case, and around 40% higher, in the second. However, from 2010 onwards, there has been no sign of increase. In the case of the scientific efficiency, there seems to be a steady (yet slight) decrease, whereas in the case of the technology efficiency no clear trend is observed. The erratic nature of the output indicators in this case (patent applications) may suggest that future studies could use some sort of moving average instead of single-year data in order to take this problem into account. The basic idea is to smooth out the typical yearly oscillations of patent applications. These figures indicate that the efficiency of R&D efforts in Brazil are not only low when compared with other countries, but they also seem to have stagnated over the last few years.

5 Conclusions

This paper has analyzed the aggregate efficiency of the Brazilian R&D efforts and compared it with those of a number of selected countries. The main conclusion is that besides investing less than other countries of reference in R&D, Brazil is also less efficient in converting those investments into scientific publications and patents. It was shown that Brazil produced less than four citable documents per USD million in R&D expenditures mainly financed by the government. As a result, the scientific efficiency of R&D expenditures in Brazil is about one third of that of

Australia, for example. Regarding the scientific efficiency of R&D personnel, Brazil also ranks among the less efficient countries in the sample. Brazil's performance regarding the technological efficiency of both R&D expenditures and R&D personal is even worse than the scientific efficiency. An analysis of the evolution of these indicators over the last years shows no sign of improvement: the efficiency of R&D efforts in Brazil is not only low when compared with other countries, but also seems to have stagnated over the last few years.

The analysis presented in this paper is innovative because the focus of the discussions is usually on increasing R&D expenditures, but very little is said about increasing their efficiency. In that sense, this paper's overview of Brazil's performance introduces new elements into the debate. Naturally, however, there are several possibilities for improving the analysis presented in this short article:



- The use of alternative measures of R&D input and outputs such as citations instead of citable documents or alternative ways of crediting scientific or technological production to countries based on scientometric criteria. Given the correlation between those alternative measures and the ones used in this paper, their use is not likely to lead to any changes in our general conclusions, but it could lead to enhancing the robustness of the results.
- The inclusion of new countries in the sample, especially to allow a more detailed statistical analysis of the data.
- The use of alternative lags between R&D inputs and R&D outputs, including some sort of analysis of sensitivity associated to the somewhat arbitrary choice of lags. The basic idea is to test whether the choice of different lags would significantly affect the results.
- The use of some way of smoothing very erratic data (for example, moving averages in the case of PCT in Brazil), especially when using cross section data for a given year.
- The expansion of the time series so that the evolution of R&D efforts efficiency could be better analyzed and panel regressions could be run.

Besides all these possible improvements, an immediate consequence of the results reported in this paper is, of course, a need to analyze the reasons behind the low R&D efficiency in Brazil. Several possible explanatory variables have been suggested in this article and in the literature:

- In both cases (i.e., in the scientific and in the technological ones) economies of scale tend to positively affect efficiency (similarly to the relation low productivity / investments).
- Future regressions may confirm that R&D intensity of a given country (for example, R&D investments as a percentage of GDP) affects R&D efficiency, although the impact of these economies of scale remains to be tested.
- As for the scientific efficiency, the available research infrastructure (for example, labs and equipment) may affect the number of published papers.
- Some language bias in favor of English-speaking countries may be observed.
- Patent applications are related to the sectoral structure (CHEN; YANG; HU, 2011). Countries with strong presence of high-tech industries tend to have more patent applications than countries that rely on traditional ones. As a result, the presence of high-tech industries in the local economy can contribute to the technological efficiency of a given country.
- The property rights protection patterns also may influence the number of patent applications and, as a result, the technological efficiency of R&D efforts.

Testing these hypotheses may have several practical implications. For example, if R&D intensity positively affects R&D efficiency, that would pose an additional challenge to ST&I policy makers in most developing countries, because dispersion of resources tends to reduce efficiency and therefore it needs to be reduced.

In spite of the long road ahead in regard to gaining a better understanding of the poor aggregate efficiency of R&D efforts in Brazil, this paper leaves no room for neglecting that aspect when discussing innovation policies in the country. The debates should not only focus on increasing the volume of resources directed to R&D activities, but also discuss a way of increasing their capacity to generate outputs at both the scientific and technological levels.

References

AKSNES, D. W.; SIVERTSEN, G.; VAN LEEUWEN, T. N.; WENDT, K. K. Measuring the productivity of national R&D systems: challenges in cross-national comparisons of R&D input and publication output indicators. *Science and Public Policy*, v. 44, n. 2, p. 246-258, abr. 2017. https://doi.org/10.1093/scipol/scw058.

CARVALHO, A. Wishful thinking about R&D policy targets: what governments promise and what they actually deliver. *Science and Public Policy*, v. 45, n. 3, p. 373-391, abr. 2018. https://doi.org/10.1093/scipol/scx069.

CAVALCANTE, L. R. Misty consensus, messy dissensus: paradoxes of the Brazilian innovation policies. *INMR - Innovation & Management Review*, v. 15, n. 4, p. 373-385, 2018. https://doi.org/10.1108/INMR-07-2018-0052.

CHEN, C.-P.; YANG, C.-H.; HU, J.-L. An international comparison of R&D efficiency of multiple innovative outputs: the role of the national innovation system. *Innovation:* management, policy & practice, vol. 13, n. 3, p. 341-360, 2011.

DANGUY, J.; de RASSENFOSSE, G.; VAN POTTELSBERGHE DE LA POTTERIE, B. The R&D-patent relationship: an industry perspective. *European Investment Bank (EIB)*, vol. 14, n. 1, p. 170-195, 2009. http://hdl.handle.net/10419/44900.

FREEMAN, C. A Schumpeterian renaissance? In: HANUSCH, H.; PYKA, A. *Elgar Companion to Neo-Schumpeterian Economics.* Cheltenham (UK): Edward Elgar Publishing Limited, 2007. p. 130-141.

GRILICHES, Z. Patent Statistics as Economic Indicators. *Journal of Economic Literature*, vol. 28, p. 1661-1707, 1990.

HANEL, P. R&D inter-industry and international technology spillovers and the total factor productivity growth of manufacturing industries in Canada, 1974-1989. *Economic System Research*, vol. 12, n. 3, p. 345-361, 2000.

JOHANSSON, B.; LÖÖF, H.; SAVIN, M. European R&D efficiency. *Economics of Innovation and New Technology*, vol. 24, n. 1-2, p. 140-158, 2015. http://dx.doi.org/10.1080/10438599.2014.897857.

LEE, H-Y; PARK, Y-T. An international comparison of R&D efficiency: DEA approach. *Asian Journal of Technology Innovation*, vol. 13, n. 2, p. 207-222, 2005.

LEYDESDORFF, L.; WAGNER, C. Macro-level indicators of the relations between research funding and research output. *Journal of Informetrics*, vol. 3, n. 4, p. 353-362, 2009. DOI: 10.1016/j.joi.2009.05.005.

LOTTI, F.; SCHIVARDI, F. Cross country differences in patent propensity: a firm-level investigation. Giornale degli Economisti e Annali di Economia, nuova serie, vol. 64 (anno 118), n. 4, p. 469-507, dez. 2005.

LUNDVALL, B.; BORRÁS, S. Science, technology, and innovation policy, In: FAGERBERG, J.; MOWERY, D.C.; NELSON, R. (Eds). *The Oxford Handbook of Innovation.* New York (NY): The Oxford University Press, 2005.

MERVIS, J. Biden proposes $250 billion investment in research. *Science,* 31 mar. 2021. Available at https://www.sciencemag.org/news/2021/03/biden-proposes-250-billion-investment-research. Consulted on: October 16, 2021.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD). *Frascati manual:* proposed standard practices for surveys on research and experimental development, Paris: OECD Publishing, 2002.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD). *Guidelines for collecting and interpreting innovation data.* 3rd ed. Paris: OECD Publishing, 205.

SCHUMPETER, J. A. *Capitalismo, socialismo e democracia.* Rio de Janeiro: Zahar, 1984 (edição original: 1942).

SHARMA, S.; THOMAS, V. J. Inter-country R&D efficiency analysis: an application of data envelopment analysis. *Scientometrics,* vol 76, n. 3, p. 483-501, 2008.

THOMAS, V. J.; SHARMA, S.; JAIN, S. K. Using patents and publications to assess R&D efficiency in the states of the USA. *World Patent Information,* vol. 33, p. 4-10, 2011.

TSAI, K. H. R&D Productivity and firm size: a nonlinear examination. *Technovation,* vol. 25, n. 7, p. 795-803, 2005.

VIOTTI, E. B. Brasil: de política de ciência e tecnologia para política de inovação? Evolução e desafios das políticas brasileiras de ciência, tecnologia e inovação. In: CENTRO DE GESTÃO E ESTUDOS ESTRATÉGICO (CGEE). *Avaliação de políticas de ciência, tecnologia e inovação:* diálogos entre experiências estrangeiras e brasileira. Brasília: CGEE, 2008.