Benchmarking University-Industry Research Collaboration in Brazil

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> The errors which arise from the absence of facts are far more numerous and more durable than those which result from unsound reasoning respecting true data. (Charles Babbage, 1832)

1. Introduction

University-Industry Research Collaboration (U-IRC) has been an important part of science, technology, and innovation policy in many regions as it is believed that more intense interactions might assist in driving business sector competitiveness. The subject has been on the agenda for many years, including in Brazil: in 1968 the Brazilian National Confederation of Industry (CNI) released a statement on industry-university interactions[1] stating that:

> "It is not a new fact that industry and university share a mutual dependency…... It is well known that the process of production makes industry a servant of science, and of its practical applications. For this very reason, research represents one of the motivations for its intimate and permanent association with the University."

U-IRC has been studied by several authors. For the case of developing countries, seeking economic catching-up, Mazzoleni and Nelson[2] argue that: "Universities and public research organizations are key institutions supporting this process of catching up". However, agreeing on the relevance of university-business interactions is one matter, but finding how to make it work for development is another problem. The same authors state[2]:

> "Successful public research programs of other countries can and should serve as broad guides for countries trying to establish their own programs, but as indicators of principles to follow, not as templates. There is first of all the problem that it is very difficult to identify just what features of another country's successful program were key to its success, and which ones were peripheral. Second, what works in one country setting is unlikely to work in the same way in another".

As the quote above suggests, few indicators have been developed to assess the state of the relationship between universities and business collaborations. In most discussions in Brazil, policy makers and

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[1] "Industria e Ensino", O Estado de São Paulo, August 4, 1968, p. 06.
[2] Mazzoleni, R., Nelson, R.R., "Public research institutions and economic catch-up", Research Policy 36 (2007) 1512–1528.

researchers start by stating that "university industry research collaboration is incipient" and conclude that it is necessary to use more government money to foster it. Rarely measures of success have been established, beyond counting the value of funds spent in fostering joint research.

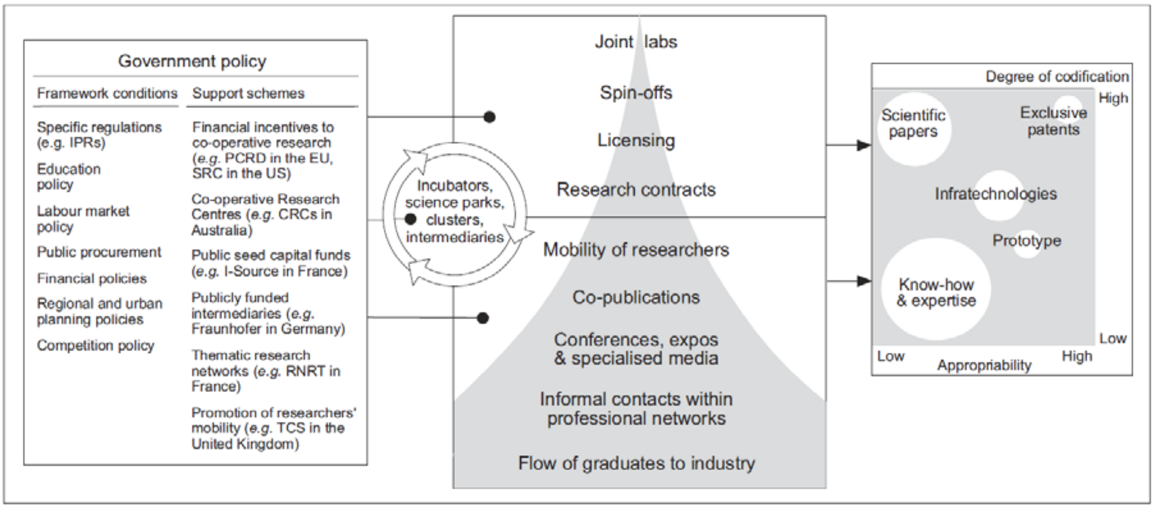
In this article we propose four non-original (but rarely explored in Brazil) indicators that might allow for a more effective tracking of policies. These are: (a) the amount of expenditures by the business sector to support university research; (b) the quantity and intensity of university-business (U-B) co-authorship in scientific articles; (c) the number of patents and derived indicators; and (d) the number of start-ups created by students and faculty of universities. These are reasonably simple indicators that can be identified and tracked by each university and by governmental agencies, allowing for a measure of success (or lack thereof) of the established policies.

1.1 Modes of Interaction Between Universities and Business

The complexity of the interaction processes between universities and the business sector is well illustrated in Figure 1. Four modes of interaction appear on the scheme, ranging from "Flow of graduates to industry" to "Joint labs". The modes chosen, and their intensity are affected by government policies such as Intellectual Policy (IP) regulations, public procurement, as well as broad characteristics of the specific economy, such as closeness/openness to competition. The flow of graduates lies at the base as it should, highlighting the educational mission of the university and also because many of the opportunities that arise from the other modes of interaction stem from the relations the professionals graduated at the university have with colleagues or former professors. A large share of the benefits to industry and to the universities that are derived from their mutual interaction are diffuse and uncodified, thus difficult to measure. At the same time, other types of interaction are more easily measurable – that would be the case for joint projects, funds related to these projects, IP licensing, joint labs, jointly authored scientific articles and reports or joint patents.

Despite the complexity of these interactions and the multiple factors at play that affect them, business sector surveys tend to frequently rank the relevance of universities and business sector interactions highly. For the case of Brazil this is highlighted in a recent report by CNI[3] (written by Carlos A. Pacheco).

[3] CNI, 2016, "Inovação: o papel da cooperação universidade-empresa", Brasília, 2016.



Source: OECD.

Figure 1. Formal mechanisms that might be involved in university-business interaction in research. (Source: OECD 2002, Benchmarking Industry-Science Relationships, p. 23)

Adam Smith alluded to this in his “An Inquiry into the Nature and Causes of the Wealth of Nations[4]”, where he described succinctly the process by which “improvements in machinery” were reached, stating a role for the users of machines, for the makers of machines (these two classes would be the business sector) and for the “philosophers or men of speculation” (those would be the present day equivalent to university professors):

> “All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade; and some by that of those who are called philosophers or men of speculation, whose trade it is not to do anything, but to observe everything; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects.”

In modern times, several surveys confirm the relevance of university collaboration for business sector innovation. In Brazil’s IBGE PINTEC surveys[5], university interactions rank repeatedly among the five or 10 most important sources of ideas for industry. A recent study by Pinho and Fernandes[6] on University-Industry Linkages (UIL) finds (Table 1) that among the countries studied, in Brazil the

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[4] Adam Smith, "The Wealth of Nations", Book 1, Chapter 1 (http://www.bibliomania.com/NonFiction/Smith/Wealth/index.html)

[5] IBGE’s innovation surveys were done in 2000, 2005, 2008, 2011, and 2014. See https://www.ibge.gov.br/estatisticas-novoportal/multidominio/ciencia-tecnologia-e-inovacao/9141-pesquisa-de-inovacao.html.

[6] Pinho M. and Fernandes, A. Table 5.5, adapted by the author in Albuquerque, E., Suzigan, W., Kruss, G., Lee, K, “Developing National Systems of Innovation: University-Industry Interactions in the Global South”. Edward Elgar Publishing, IDRC, January 30, 2015 (available in open access at https://www.idrc.ca/en/book/developing-national-systems-innovation-university-industry-interactions-global-south).

relevance attributed by firms to Public research institutes and Universities is the highest, ranking, respectively, 4th[d] and 3[rd], while, for example, in the U.S. firms ranked Universities as 6[th] and in China 9[th]. The authors state that:

> "These data call into question the common notion that in emerging countries UILs are missing or weak. There is no clear and sound evidence to support this conjecture. Nevertheless, data on the importance attributed by firms to universities as a source of information for innovation cannot be considered as evidence of stronger or more frequent relationships in developing countries. As a matter of fact, there are no data to support any of these positions."

Table 1. Sources of information used by firms for innovation. The column % shows the percentage of answers pointing tht factor on the respective line; the column R shows the ranking of the factor on the line. (Source: Albuquerque et al.[6], Table 5.5, adapted by the author of this article)

Sources	India		China		Malaysia		Mexico		Brazil		So.Africa		USA	
	%	R	%	R	%	R	%	R	%	R	%	R	%	R
Firms´own manufacturing process	81	1	76	3	87	1	49	4	75	1	49	1	78	2
Customers	72	2	89	1	71	3	64	1	68	2	35	2	90	1
Public research institutes	17	12	51	13	37	12	27	9	55	4	3	8	na	na
Independent suppliers	41	6	53	12	46	9	40	6	45	9	24	3	61	4
Technical publications and reports	51	4	56	9	62	5	44	5	50	7	4	7	na	na
Affiliated suppliers	38	7	63	7	80	2	25	11	50	6	na	na	na	na
Universities	**14**	**13**	**56**	**9**	**34**	**13**	**28**	**8**	**60**	**3**	**5**	**5**	**36**	**6**
Competitors	33	8	71	5	54	7	34	7	37	11	13	4	41	5
Internet	55	3	71	4	62	4	57	2	49	8	Na	na	na	na
Consulting or contract R&D firms	24	11	56	9	57	6	20	12	29	12	4	6	34	7
Fairs and expositions	29	10	59	8	42	10	53	3	53	5	na	na	na	na
Indigenous knowledge systems	51	4	82	2	41	11	na	na	42	10	na	na	na	na
Cooperative or joint venture with other firms	29	9	68	6	54	8	27	9	25	13	na	na	50	3

A note of caution about U-IRC was sounded by Mansfield over twenty years ago who addressed the role of the U-B interactions[7], demonstrating that, if universities have a contribution to the innovation creation process, they cannot act alone: the role of the business sector is paramount. He found that academic research made an essential and immediate contribution to less than 10% of the new products or processes introduced by companies in the United States. This percentage might have increased in recent years[8] given the enactment of governmental policies to intensify university-industry collaboration, implemented in the U.S. and elsewhere. . Still, the data from 2013 shown in Table 1 shows that in the U.S. universities rank 6[th] in relevance as sources of ideas for industry innovation. Data from NSF survey "National Patterns of R&D Resources" is consistent with this observation, showing

[7] E. Mansfield, "Contributions of new technology to the economy", in Technology, R&D and the Economy, ed. Bruce Smith e Claude Barfield. P. 125 (The Brookings Institutions, Washington, DC (1996).
[8] F. Bloch and M. Keller, "Where Do Innovations Come From? Transformations in the U.S. National Innovation System, 1970-2006", The Information Technology & Innovation Foundation, 2009. http://www.itif.org/files/Where_do_innovations_come_from.pdf?_ga=2.167260217.625249229.1530464658-833851808.1523391489.

that industry sector expenditures to fund collaborative R&D with universities in the U.S., from 1953 to 2016, has never been above 1.2% of the total industry R&D expenditures[9].

Recognizing that the role of the business sector in carrying out internal R&D is essential for innovation and competitiveness is especially relevant for developing countries, where often the business sector and the government fall prey to the illusion (or, worse, delusion?) that university research will substitute for non-existent business R&D, through a magical process of "technology transfer" from scientists and engineers in universities to accountants and lawyers in industry. The CNI report[3] mentioned above is explicit in this matter, outlining the importance of "absorptive capacity" by the business sector. Without some knowledge of and teams dedicated to R&D, it is difficult for firms to benefit from university R&D (Cohen & Levinthal, 1990). Interestingly the same sentiment was voiced, 99 years before, by F.B. Jewett[10], the first director of Bell Laboratories, when he described his view on absorptive capacity:

> "… to succeed in its proper field, industrial research must receive a continual stream of capable men and women thoroughly trained in methods of scientific research, thoroughly grounded as to the geography of knowledge, and competent to appreciate any extensions in its boundaries and capable of immediately cultivating such extensions for the benefit of the particular industrial research organization · with which they are connected. ."

Thus, it is not enough to just increase technology transfer capacity from the university lab to industry - it is also necessary to have capacity at the firm level to be a willing and able partner with university to make such collaborations fruitful.

The challenge we address in this paper is to show that it is possible to construct more meaningful indicators for understanding university-industry relationships. To increase our understanding of such processes in Brazil, we need better measurement and evaluation. Multiple indicators can assist in assessing the state of university-business interactions. For the present discussion we analyze four indicators of U-IRC in Brazil:

a) Amount of expenditures for industry-sponsored research at a university.

b) Intensity of industry and university researcher co-authorship in scientific articles

c) Patent portfolio, intensity of industry and universities co-titleship in patents, and licensing.

d) Number of start-ups created by students and faculty from a university.

[9] NSF, "National Patterns of R&D Resources: 2015-2016, Data Update", Table 2, https://nsf.gov/statistics/2018/nsf18309/#chp2.

[10] Jewett, F.B., "Industrial research with some notes concerning its scope in the Bell Telephone System", Presentation at the 333d Meeting of the American Institute of Electrical Engineers, Philadelphia, Pa., October 8, 1917.

In each case we will show examples to demonstrate that it is possible and useful to define such indicators.

2 Business sponsored research

One way to assess the intensity of U-IRC is to measure the volume of financial resources allocated by industry to universities yearly to support sponsored research activities. In most universities contracts for sponsored research with industry are coveted, as a source, not only to complement funds from governmental sources, but to support new and pressing research challenges for the academic research environment. Collaborative research also has an important role in training students and post-docs, especially in applied fields. In the U.S. and Europe, universities have Offices of Sponsored Research, that assist the investigators in identifying and developing opportunities for joint research projects with industry. In Brazil most research-oriented universities have organized Innovation Agencies (or Innovative Technology Nuclei) to this end.

In Brazil, industry sourced funds are especially interesting, and for this reason valued by the research community, as they can be used with much more flexibility than governmental funds and also because they can be used for paying additional salary to some of the investigators associated with the contracted project. Governmental organizations, such as FINEP, FAPESP, and EMBRAPII have programs to foster university-industry research collaboration, offering funds to be matched by industry and by the universities that host the research activities.

Even though U-IRC has been fostered in Brazil, there are very few measurements of its intensity or impact. The research funding agencies tend to have data about the yearly value spent in collaborative projects, but few universities publish openly their data on the value of the research contracts with industry. In the state of São Paulo, only the State University of Campinas (Unicamp) presents this data as a time series in its Statistical Yearbook[11].

For this work we used the data published by Unicamp, which is publicly accessible and covers the period from 1995 to 2017. We also obtained a specially built time series from USP, covering the period from 2006 to 2015. In both cases, the data includes only research contracts, and not funds donated for other purposes.

For the universities in the U.S. we used data published by NSF in their National Center for Science and Engineering Statistics (NCSES)[12], which presents selected data for individual institutions on doctorates, graduate students, funding and expenditures from four NCSES surveys, including 2,014 universities and colleges. We also referred to the MIT Report of the Treasurer for 2010 and 2015, which are available at MIT's website.

[11] UNICAMP, https://www.aeplan.unicamp.br/anuario/anuario.php
[12] https://ncsesdata.nsf.gov/profiles/site

To compare the data, we converted the nominal values using the Purchase Power Parity (PPP) exchange rate, published by the World Bank[13].

Table 2. Descriptive data for the years 2010 and 2016 for MIT, All U.S. universities covered on NCES, Unicamp, and USP. (Sources: see text)

	MIT		All U.S. Univ in NCES		Unicamp		USP	
In US$	2010	2016	2010	2015	2010	2016	2010	2016
Total revenues	2.663,1	3.426,8	-	-	1.295,1	952,9	2.507,4	2.175,1
Research expenditures	677,1	946,2	61.253,7	68.667,8	723,3	536,6	1.931,9	1.707,2
Governmental	458,0	504,4	41.327,7	41.689,3	178,1	144,1	532,1	410,4
Institutional funds	102,9	92,1	11.940,5	16.711,7	509,8	373,2	1.332,7	1.246,6
Business	68,9	159,5	3.197,6	4.000,6	35,4	19,3	67,1	50,1
Nonprofit organizations	12,5	94,8	3.740,1	4.237,0				
All other sources	34,9	94,8	1.047,8	2.029,2				
HERD/Total Revenues	25,4%	27,6%	-	-	55,9%	56,3%	77,0%	78,5%
Business/Gov Funding Agencies %	15,0%	31,6%	7,7%	9,6%	19,9%	13,4%	12,6%	12,2%
Business/Total revenues %	2,6%	4,7%	-	-	2,7%	2,0%	2,7%	2,3%
Faculty	1.025	1.040			1.750	1.910	5.865	5845
Undergraduate students	4.299	4.524			17.083	19.581	57.300	58.823
Graduate students	6.267	6.852			14.571	16.137	31.662	37.509
PhDs awarded	582	646			826	966	2.338	3.086

HERD: Higher Education R&D expenditures
Data sources:
Financial: explained in the text
MIT Students: http://web.mit.edu/registrar/stats/yrpts/index.html
MIT Faculty: http://web.mit.edu/ir/pop/faculty_staff.html
USP, Unicamp: Statistical Yearbooks

Before analyzing the data shown in Table 2, we must comment on a discrepancy resulting from the way the data is calculated for the institutions considered. This refers to the line "Institutional Funds", where it can be seen that the values for Unicamp and for USP are substantially larger than the values for MIT. For the year 2010, the data for Unicamp is approximately five times higher than that of MIT, while USP's is 14 times. The reason for this disparity seems to be due to the use of different ways to estimate the value of institutional funds devoted to R&D.[14].. The total cost of the institution dedicated to R&D is calculated considering this full time additional salary and its impacts in the other costs of the institution. Before the calculation, the costs of hospitals, museums and retirement pay are subtracted

[13] http://data.worldbank.org/indicator/PA.NUS.PPP?locations=BR
[14] The data for USP and Unicamp is obtained following the specifications of the OECD Frascatti Manual, which determines that a fraction of the total costs of the institution must be ascribed to the R&D activities following an estimate of the time dedicated by faculty and staff to these activities. This determination involves difficulties well recognized internationally and is highlighted in the OECD Frascatti Manual where the suggestions for the procedures for this estimation are the subject of a special Annex[14]. One of the recommendations suggests that the estimation of the costs and personnel dedicated to R&D in higher education institutions should be based on surveys of the time dedicated to each faculty activity or, if such surveys are not viable, on other ways to assess the fraction of R&D in the total costs of higher education[14]. The estimates for Unicamp and USP are described in detail in the Part A of Chapter 3 of FAPESP's publication on S&T Indicators, 2010. http://fapesp.br/indicadores/2010/volume1/cap3-Parte-A.pdf

from the total as these do not relate to R&D[15].In the case of MIT, we were unable to obtain information concerning how the institutional funds are specified.

Considering the discrepancy discussed above, we found it more meaningful to use, for the comparison of business research contracts intensity, a calculation of the ratio between the expenditures covered with business contracts and the expenditures covered with governmental contracts. This ratio is meaningful because most universities rely on these two sources for supporting their research, particularly the latter, for both public and private universities. Other sources may also be important to some universities but at a lower percentage (at MIT, for example, approximately 30% of research expenditures are generated from other sources including non-profits (foundations) as well as institutional investments and gifts). This is the data shown in the line "Business/Gov Funding Agencies %" of Table 2.

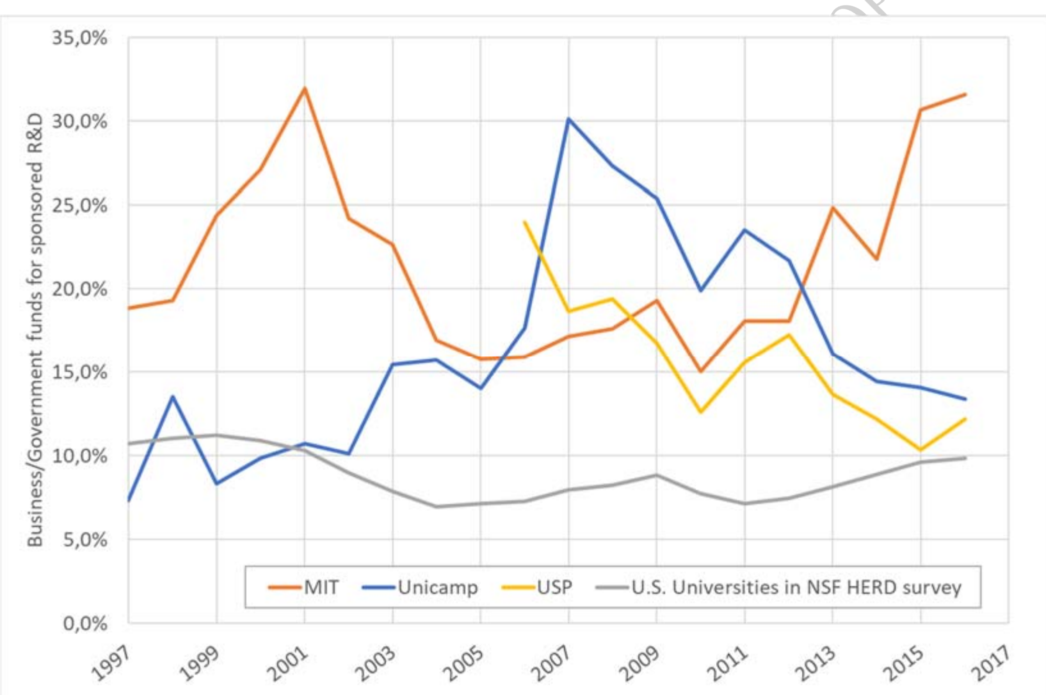

Figure 2. Ratio of business to governmental agencies funds spent in research at MIT, Unicamp, USP, and at the set of U.S. universities included in NSF's NCSES database. (HERD= Higher-education Expenditures in R&D)

Figure 2 shows the time series for each entity (or set of entities), according to the availability of the data. Features worth mentioning are:

a) Both for Unicamp and USP the ratio of business to government (B/G) lies above the average for the set of U.S. entities covered in the NSF HERD survey (see Figure 3 for a comparison using the 25 universities in the U.S. with the highest R&D expenditure)

b) For Unicamp B/G ranges from 7% to 30%, from 1997 to 2015, while for USP the range is from 25% to 10% in the period from 2006 to 2015.

[15] It might be argued that hospitals and museums contribute to the R&D activities in a university, so that the estimation obtained following the algorithm described must be considered as a lower bound.

c) For the years between 2006 and 2012 the B/G ratio for Unicamp was higher than that of MIT.

d) For MIT there is a steep decline after 2001, which might be related to the economic troubles started on that year and compounded by the recession after 2008.

e) Starting in 2010 there was a steep rise in the B/G ratio for MIT, reaching 32% in 2016.This could be attributed in part to coming out of the Great Recession in the U.S.

f) For both USP and Unicamp the B/G ratio has been decreasing since 2007, a decline that seems to have worsened after 2012, but that can be understood considering the economy and political troubles that have been afflicting Brazil since then[16].

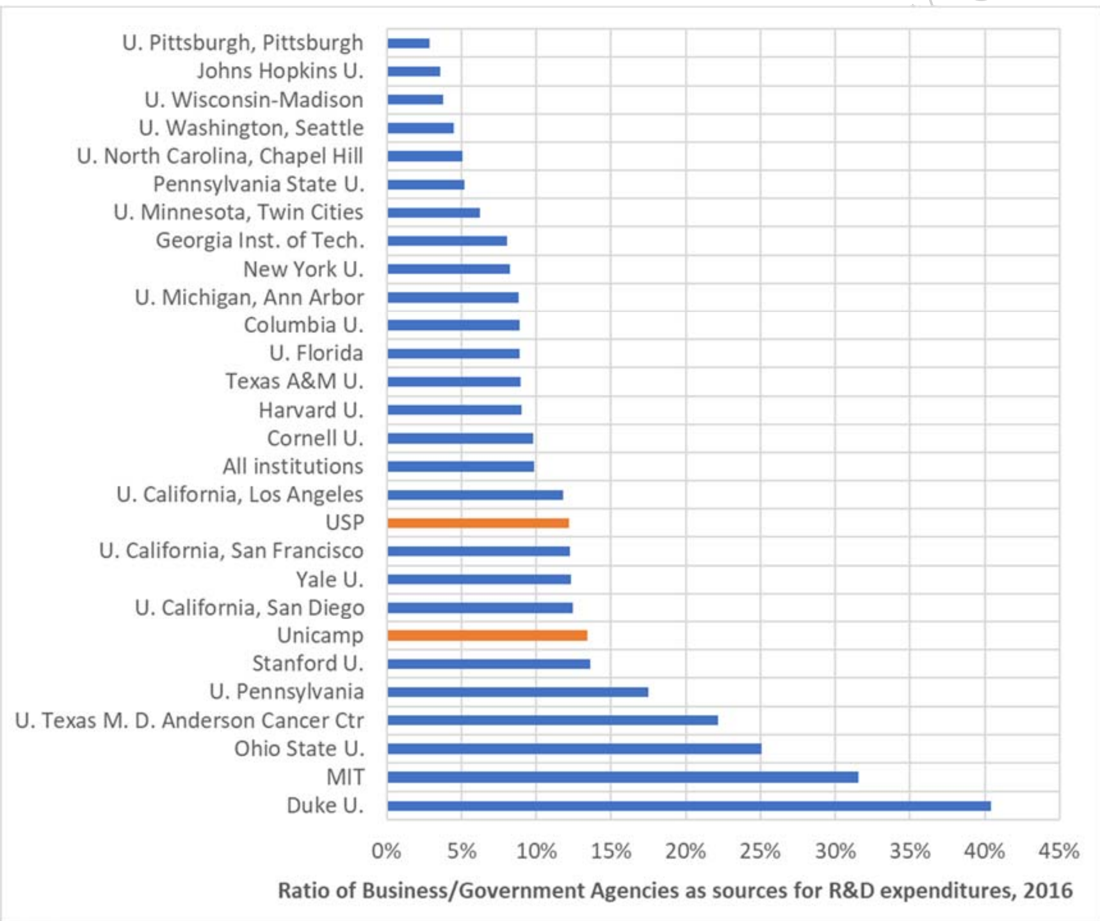

Figure 3. Ratio of Business/Governmental Agencies funds for R&D spent at the 25 universities in the U.S. which have the highest R&D expenditures and for USP and Unicamp. (Source for U.S. Universities: NSF HERD Survey, https://ncsesdata.nsf.gov/herd/2016/html/HERD2016_DST_21.html; for USP and Unicamp this work)

Not only, as we wrote in item (a) above, the ratios verified at USP and Unicamp are above the average for the U.S. universities, but also their indicator places them (in a good position) among the 25 U.S. universities with the largest R&D expenditures. Figure 3 shows the data for the Business/Governmental Agencies ratio, for the funds spent on R&D at the 25 universities in the U.S. with the highest R&D

[16] Data recently announced by Unicamp for the year 2017 points to a recovery, raising the Business/Government fraction to 23% (https://www.inova.unicamp.br/noticia/correio-popular-noticia-balanco-das-parcerias-firmadas-pela-unicamp/).

expenditure, and for Unicamp and USP. It can be seen that there are six outliers (Duke, MIT, Ohio State, U. Texas M.D. Anderson Ctr, and U. Pennsylvania), while the other large U.S. research universities display percentages below 14%.

Before concluding this section, it is worth mentioning that USP and Unicamp are among the strongest research universities in Brazil. Thus, the fact that they display indicators for the intensity of university-industry contracts higher than the average for U.S. universities and in the same range of intensity found at MIT should be generalized with care, or not at all. It is very likely that some research-oriented universities in Brazil display a similar level of university-industry interactions as USP and Unicamp, in Figure 2. Entities as ITA, UFSCAR, UFRJ, UFSC and UFMG come to mind, but unfortunately there is no available data at present[17]. Clearly, as this data suggests, it is misleading to state that there is little university-business collaboration in Brazil, as many do.

3 Co-authorship in scientific articles

Another indicator for U-IRC which is widely available and covers numerous institutions is the number (and percentage of the total number) of articles in which researchers from a given university are coauthors with researchers from the business sector. The analysis presented here uses data from the Web of Science, obtained through searches performed at the normal WoS interface available to researchers.

While the database InCites carries data for the percentage of articles with industry co-authorship, their data is incomplete as the database is not yet able to classify correctly the nature of a large number of business organizations in Brazil (and elsewhere, for that matter). To obtain the data shown here we devised a search routine especially built to unveil the business sector in Brazil. The procedure involved obtaining the data for all scientific documents in the database with at least one author in Brazil (>300,000 records), then analyzing the organizations to which the authors were affiliated (>22,000), and then classifying among these the ones which were in the business sector. In the end we had more than four thousand organizations. At this point we ran a search looking for items in which the authors were in one of the 4,000+ business sector organizations and each and any university (obtained in a separate list).

[17] While this work was being finished we obtained data for ITA: between 2010 and 2017 the Business/Government agencies ratio was between 42% to 88%. In 2017 the percentage was 87%.

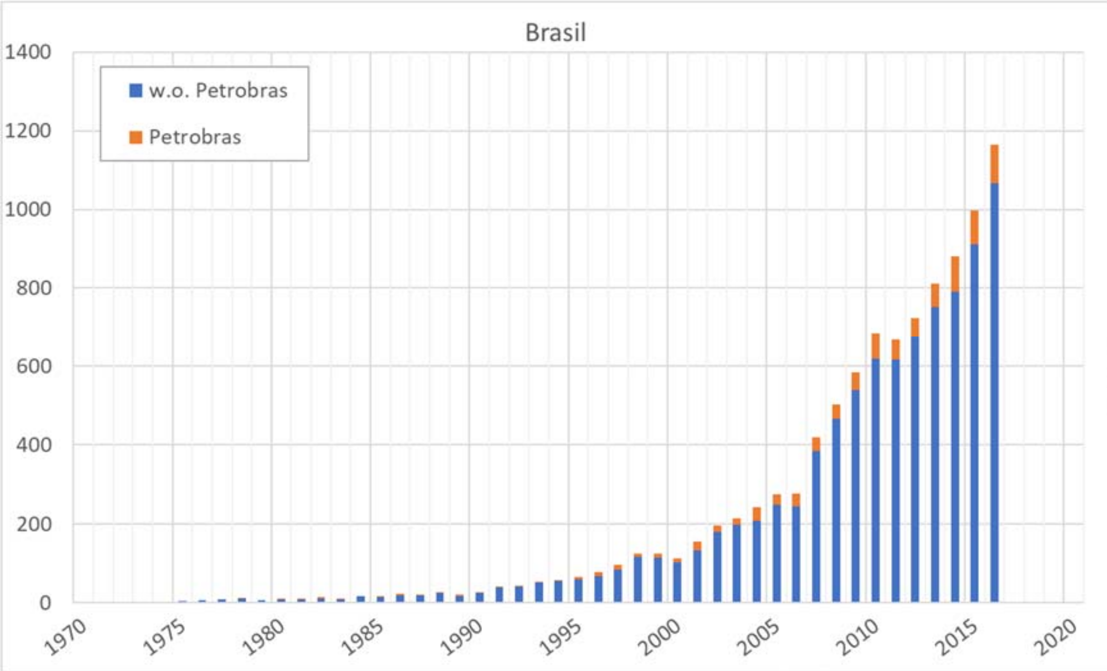

Figure 4. Quantity of articles, by year, with authors in universities in Brazil and coauthors in the business sector. We included a separate mark for the number in each year with coauthors from Petrobrás to make it clear that, although relevant, the set is not dominated by these.

The result is shown in Figure 4, which shows the evolution of the quantity of articles with coauthors in the business sector and in universities highlighting, in the orange bars, the quantity in co-authorship with researchers at Petrobras.

While the growth seen in Figure 4 is interesting, it is also relevant that the fraction of the articles with university and business (U-B) co-authors in the total scientific production of Brazil and São Paulo is also growing (Figure 5).

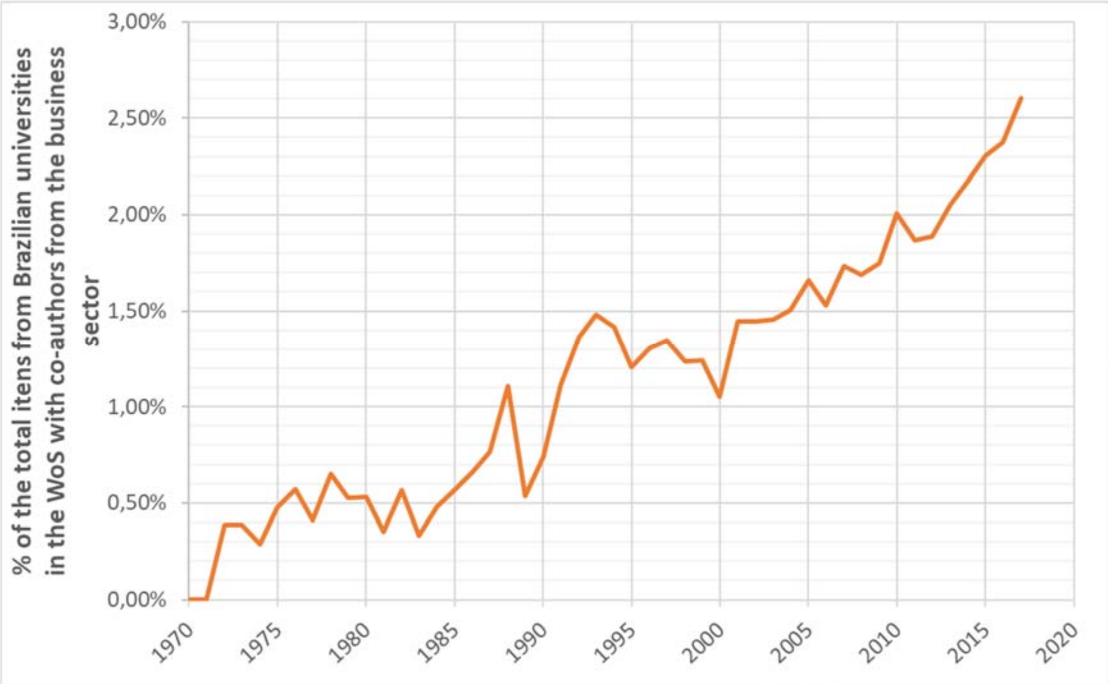

Figure 5. Fraction of the total scientific production in Brazil, São Paulo, and Brazil outside São Paulo that have co-authors from universities and business.

There seem to be three periods with different behavior in the evolution of U-B co-authorships in Brazil: first, from 1972 to 1984 the tendency shows a stability around 0.5%. Between 1985 and 2004 there is a pronounced growth, albeit with large oscillations, while the percentage reaches 1.5% in 2004. Then, after 2006 the curve shows a steep ascent, becoming more accelerated for the years after 2012.

Even though there is encouraging growth, an international comparison (Figure 6) demonstrates that there is room to grow. Brazil is at 2.4% and the State of São Paulo at 2,5%, while South Korea, Germany and France have percentages between 3.8% and 4.4%.

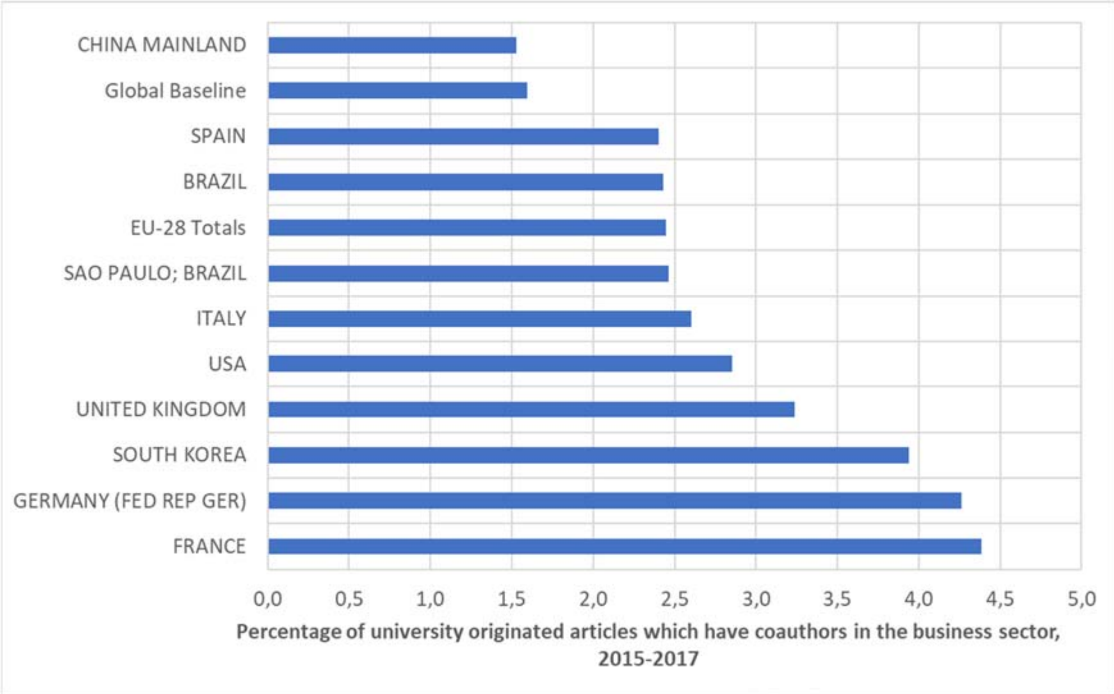

Figure 6. Fraction of articles with co-authors from universities and the business sector in a set of countries and regions (Source: For Brazil and São Paulo, author's measurements in the Web of Science; for the other regions: Clarivate's Incites).

The percentage of U-B co-authorships for the universities in the state of São Paulo, between 2015-2017, at 2,5%, was similar to the one found in the Europe of 28 countries, 3% above that found in Spain, and 54% above the Global baseline. On the other hand, it is 44% below that found in France or 42% below the one in Germany.

3.1 U-B co-authorship – how some Brazilian universities fare

Figure 7 shows how the U-B co-authorship percentage has been evolving for some research-intensive universities in Brazil. ITA (Aeronautics Technology Institute) has the highest ratio, around 6%, with a steep climb after 2007, even though over a small total number of publications (188 items in 2016). UFRJ (Federal University of Rio de Janeiro) displays also strong growth after 2013, almost doubling its percentage in only four years. USP, Unicamp and UFSC (Federal University of Santa Catarina) display a solid continued increase for the last several years, with more intense growth in the last two years.

Figure 8 shows a comparison of the U-B co-authorship rate for selected universities in Brazil and selected universities in the USA. The data indicate that even in a country with a strong tradition of university-industry research collaboration such as the USA, there is a range of experience with respect to this indicator.

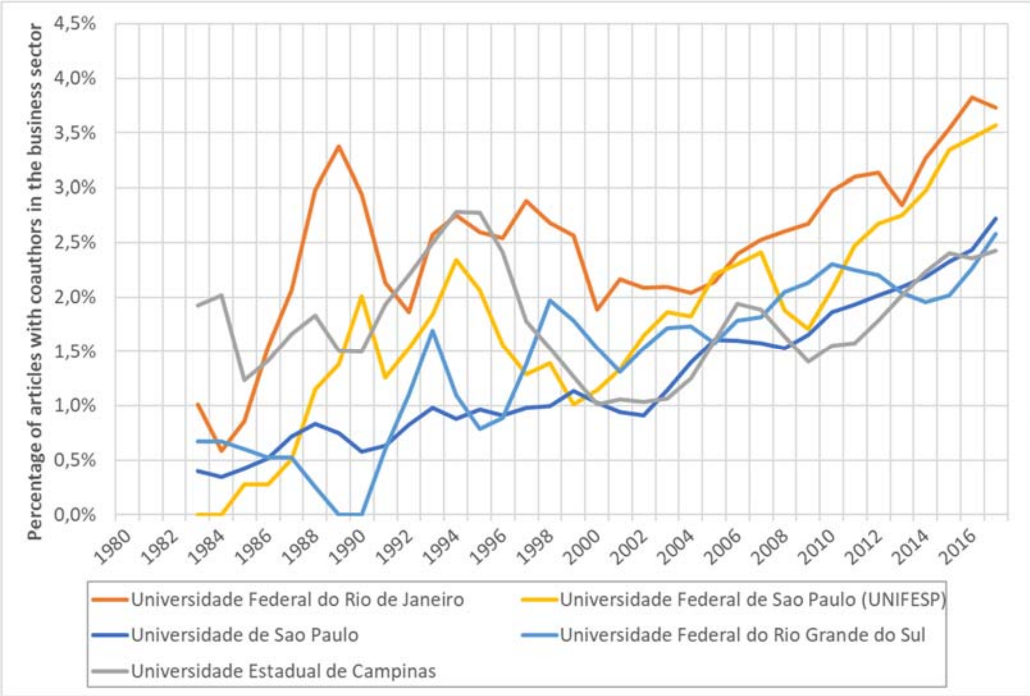

Figure 7. Evolution of the U-B co-authorship fraction of the total publications for the five universities in Brazil with the largest number of co-authored articles with the business sector.

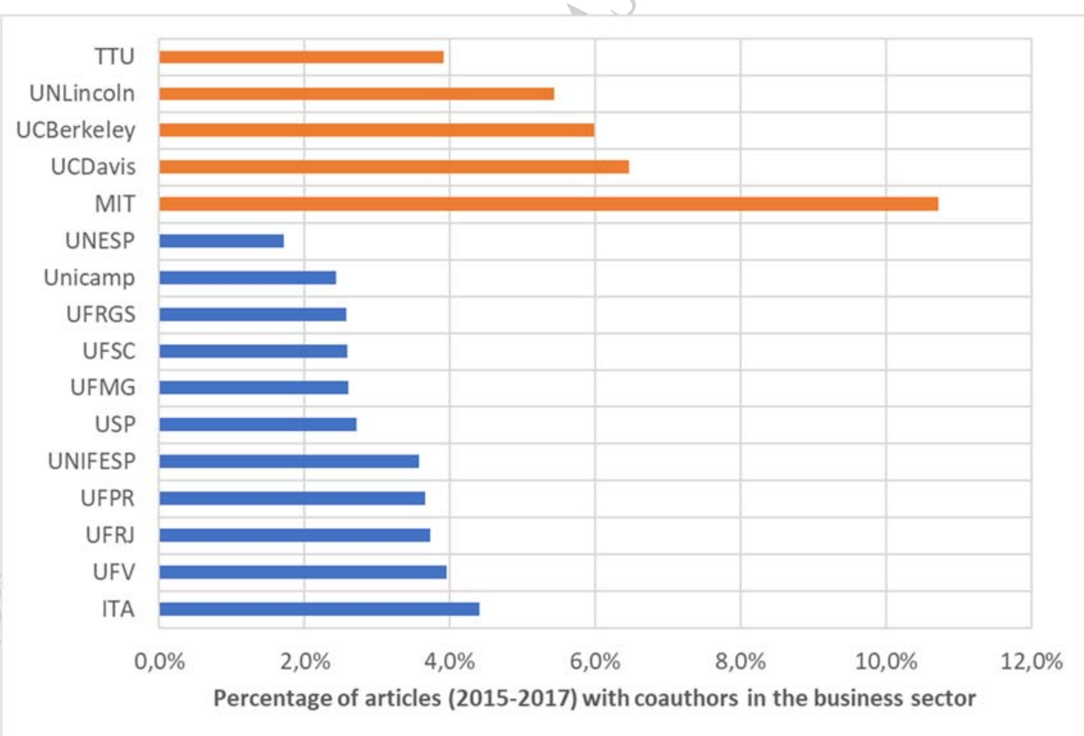

Figure 8. Comparison of U-B co-authorship rate for the ten universities in Brazi with the largest number of co-authored articles with the business sector, and some universities in the USA, considering the period 2015-17 (Source: measurements described in this work for the all universities shown).

MIT is the strongest in this set, with a U-B co-authorship percentage of 11% while Texas Tech University (TTU)[18] has an intensity of 4%. The Brazilian universities range from 1.7% (UNESP) to 4.4% (ITA).

It is clear from Figure 8 that the co-authorship rate for universities in Brazil lags behind that observed for universities in the U.S.. The rate of growth in the number of articles in co-authorship with industry in Brazil points to a convergence in due time, but it is important to mention here some differences in the environment the universities operate in in Brazil and in the U.S. The main factor, in our view, relates to the fact that the business sector in Brazil employed, in 2014, 59,364 researchers[19], while in the U.S. the number of researchers employed in the business sector, in the same year, was close to 960,000 (FTE)[20]. Thus, the number of potential co-authors from industry in the U.S. is 16 times larger than in Brazil.

A characteristic that differs the case of UFRJ from the other Brazilian universities used in the comparison is that for UFRJ the weight of collaborations with Petrobras is very high. In the period 2015-2017 for all universities covered here the co-authorship with Petrobrás amounted to 14% of the total articles with business sector co-authorship, while for UFRJ this percentage was 34%. This is to be expected, considering the geographic proximity between CENPES, the Petrobras research center and the UFRJ campus, plus the effective work of COPPE-UFRJ in developing research partnerships.

3.2 U-B co-authorship – main business sector collaborators

It is interesting to look at the list of companies most frequently co-authoring with academic researchers. This research uncovered 1,148 companies as co-authors with university researchers in Brazil[21]. The ones with more than 40 articles in the sample are shown in Table 3.

[18] TTU and University of Nebraska Lincoln were chosen here as FAPESP has developed research collaborations there and held a FAPESP Week symposium in both campuses in 2017. Both are strong research-intensive universities albeit located at a distance from high technology hubs like Massachusetts or California.

[19] MCTIC, Indicadores de C&T&I, http://www.mctic.gov.br/mctic/opencms/indicadores/detalhe/Recursos_Humanos/RH_3.1.2.html.

[20] OECD, Main Science and Technology Indicators, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB#

[21] By mid-January 2018 a report by Clarivate Analitycs was published under the title "Research in Brazil A report for CAPES by Clarivate Analytics". This report has data for university-industry co-authorship in Brazil for the period 2011-2015 with the observation: "This could be partly due to how corporations are defined in the Web of Science, which may miss the domestic SMEs that the Brazilian government has been so keen to support." The data shown here does not suffer from this deficiency as it was searched independently with a methodology that allowed for the consideration of more than one thousand companies as co-authors. First we obtained all articles with authors in Brazil. Then we obtained the list of organizations with co-authors in each article and classified the organizations to identify the ones belonging in the business sector.

Table 3. The 40 companies with more co-authored articles with universities in Brazil (2011-2017).

Rk	Name	Qty
1	Petrobras	1050
2	Novartis	174
3	Pfizer	118
4	Roche	94
5	GSK	94
6	IBM	93
7	Vale/ITV	84
8	Merck	78
9	Eletrobras	72
10	AstraZeneca	72
11	Fibria	70
12	Westat	64
13	Janssen	57
14	Embraer	56
15	Bayer	55
16	Monsanto	54
17	Agilent	52
18	Braskem	51
19	Boehringer Ingelheim	49
20	Sanofi	49

Rk	Name	Qty
21	Eli Lilly	47
22	Syngenta	47
23	Novo Nordisk	45
24	Amgen	42
25	Dow Agrosciences	42
26	Itaipu	40
27	Bristol-Myers	39
28	Genzyme	38
29	Whirlpool/Embraco	38
30	Fundecitrus	36
31	Ericsson	36
32	Genentech	34
33	IPEF	33
34	Suzano	31
35	CEMIG	31
36	AT&T	30
37	Furnas	26
38	Microsoft	26
39	Apis Flora	26
40	Votorantim	25

Petrobrás appears as the main corporate coauthor, which is to be expected considering that the company has strong R&D activities in Brazil and has also a strong program for interacting with universities, as mandated by federal legislation.

Pharmaceutical companies appear prominently among the main coauthor's employer. This is a feature that became more evident in the last 20 years, following the increase in the mumber of publications in Health Sciences by Brazilian authors.

Among the 40 main co-authoring companies shown in Table 3, 15 are Brazilian. Vale ranks 7th and has been recently increasing its participation as a coauthor, especially since the organization of the Instituto Tecnológico Vale, in 2012. Eletrobrás ranks 9th, and Fibria appears as 11th. Other companies of the pulp and paper sector join Fibria, as Suzano (34th) and those associated to IPEF, a private institute created by a consortium of companies in that sector. Embraer ranks 14th and has been raising its classification recently. Apis Flora, initiated in 1982, is an interesting case: a small company with a strong R&D activity and beneficiary of a number of FAPESP's Small Business Innovative Research grants.

The predominance of foreign companies in the list reflects the small number of Brazilian companies with advanced R&D activities. It also shows that universities in Brazil have capabilities to contribute to industrial R&D, and these capabilities seem to have been noticed more by foreign companies than by Brazilian ones. This is consistent with other indicators such as patents registered by the business sector, or the number of researchers working for companies in the country.

4 Patent portfolio, intensity of industry and universities co-titleship in patents, and licensing

Patents are a primary tool for measuring innovation both in universities and more broadly in countries. Increasing patenting at universities has been a central goal of many of the innovation policies implemented in Brazil in the past two decades. Patents are also useful instruments for facilitating university-industry interactions, be it through joint ownership of title or through licensing of university-owned patents. In this section, we consider data related to patenting activity as indicators of quantity and/or quality of U-IRC.

The most used indicator in Brazil for demonstrating the contribution of universities to innovative activities so far has been the quantity of patents filed. Most universities highly value this number and are proud of their growing patent portfolio. Many established Innovation Agencies (which have functions similar to the U.S. with Technology Transfer Offices) have done effective work with their faculty to develop a culture for valuing intellectual property rights, with reasonable results. So much so that in recent years universities figure among the largest patent filers in Brazil, as opposed to what is seen in more developed economies where industry appears higher in this kind of ranking.

Table 4. Patents filed per 100 Faculty and Articles published per 100 Faculty for some universities in Brazil and in the U.S. in 2016. (Sources: AUTM Database for U.S. universities' patents, web sites of universities for faculty; INPI for Brazilian universities'patents; Incites for articles).

University	New Patents Filed	Articles WoS	Faculty	Pat. Filed per 100 Faculty	Articles per 100 Faculty
CalTech	355	3372	300	118,3	1124
MIT	470	7109	1040	45,2	684
Stanford U.	288	9420	2219	13,0	425
Harvard	314	41424	2459	12,8	1685
Nebraska, Lincoln	174	2053	1699	10,2	121
U. California	1329	39502	22110	6,0	179
Boston U.	122	4054	3870	3,2	105
UNICAMP	62	3072	1910	3,2	161
Univ. of Massachusetts	133	4670	5712	2,3	82
UFPR	53	1567	2411	2,2	65
Univ. of Central Florida	49	1412	2481	2,0	57
UFMG	70	2275	3465	2,0	66
TTU	29	1638	1740	1,7	94
USP	60	9524	5845	1,0	163
UFSCAR	13	1139	1437	0,9	79
UNESP	30	3836	3631	0,8	106
UFRJ	15	2855	4066	0,4	70

In Table 4 we show the ratio of the number of patents filed for to the size of faculty in some Brazilian universities and compared these to data obtained for universities in the U.S. (). Consistently with the observations by Carlos Pacheco[3], we find that this ratio for Brazilian universities lags the one found in the U.S. However. We must caution the reader about the difficulty of considering the actual workforce to be used in the denominator, as universities in the U.S. normally have more public support for hiring research associates (this is a similar difficulty as the one we discussed in section 2 for estimating the institutional funds ascribed to research activities).

Considering the caveat discussed above, it seems more advisable to compare the quantity of patents filed (2016) with the R&D expenditures for the university (data for 2016) (Figure 9). Using the R&D expenditures avoids the doubts about the counting of personnel involved in the creation of the patents. We find that patents do not come cheap: the graph shows that U.S. universities file a patent for every US$ 2,7 million spent in R&D. The data point for Unicamp indicates that this university is at 40% of the trend line, while USP is at 12%.

While the quantity of patents filed is a basic indicator of the potential for transferring technology to the business sector, another relevant indicator is the quantity of patents in which the university shares title with industry. This indicator must be regarded with care, as the practice in many universities in Brasil is to release title to patents (in exchange for benefits) obtained in joint research with industry to avoid the complex process required for the licensing of technology from public organizations. Not having title to the IP does not mean the university cannot receive benefits accrued from licensing or selling of the patent – these are usually written into an agreement between the university and industry.

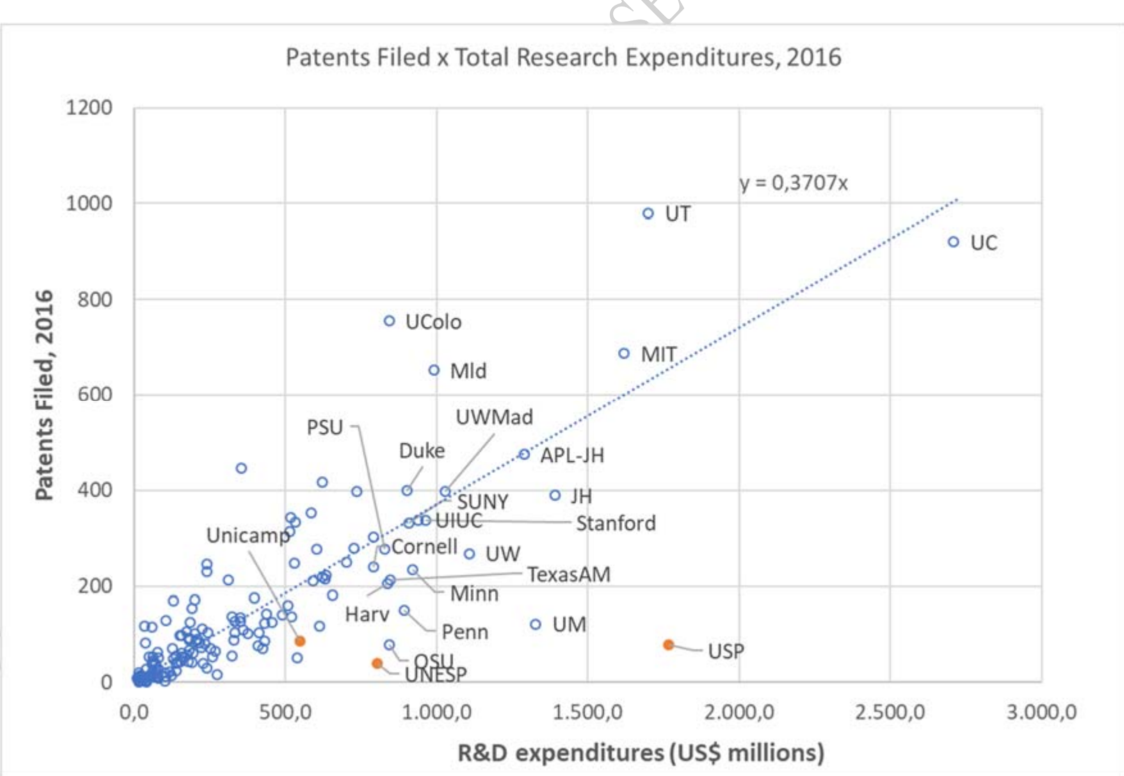

Figure 9. Patents Filed versus R&D expenditures for 160 universities in the U.S. (Source: AUTM Annual Report, 2016) and for USP and Unicamp (UT: U. of Texas System; UC: U. of California System).

In principle the information about joint titleship to patents can be obtained from INPI or other databases, but most universities do not value this indicator. An internal publication by INPI illustrated this indicator for some Brazilian universities for the period 2004-2008[22]. They found that Unicamp filed 272 patents, of which 43 had a shared title; of the sharing entities 15 were companies. For USP the number filed was 257, of which 113 had shared title; there were 14 companies among title sharing entities. UFMG filed 154 patents and had 7 companies sharing title, while UFRJ filed 141 patents in the same period, having 6 companies sharing title.

A third indicator related to intellectual property is the percentage of patents licensed and the amount of revenues obtained through licensing. There is a lot of misunderstanding in Brazil about this, with a general supposition in universities and in government that most universities in the U.S. make great amounts of money from licensing IP. The data in Figure 10 shows that about 50% of the universities that participated in the AUTM survey obtain from licensing a gross revenue which is less than 1% of their yearly R&D expenditures, 70% obtained revenues below 2% of the R&D expenditure, and only three universities (out of 164) obtained, in the year in question (2016), a ratio higher than 20%. Note that the data refers to the gross revenue, indicating an even more meager situation if we consider net revenues. For the Brazilian universities we do not have data about licensing revenues, except for Unicamp, which publishes this information in their Statistical Yearbook. For 2015 and 2016 the licensing revenues were 0,2% and 0,1% of the R&D expenditures.

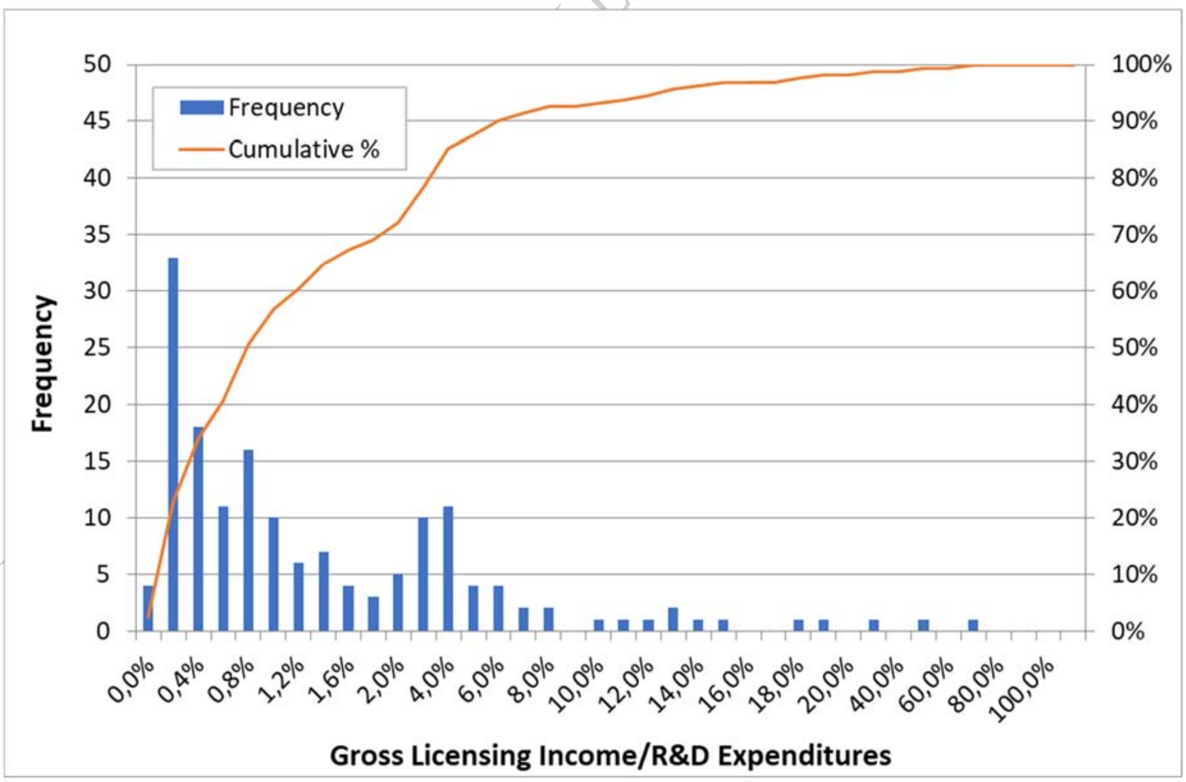

Figure 10. Distribution of the ratio (Gross Licensing Income/R&D Expenditures) for 164 universities in the U.S. in 2016 (Source: AUTM Annual Report).

Even if the licensing revenues are relatively small, this does not mean filing and licensing patents is irrelevant. Transferring technology through licensing is one of the many contributions of universities to the economy, and this adds to other actions. The mistake would be to consider that licensing revenues would substitute for public revenues to support research. The recent CNI Report[3] refers to this matter, citing that according to John Fraser of AUTM *"no longer is licensing income seen as a comprehensive indicator of success"*.

5 University related start-up companies

Finally, the number of startups created by students, faculty, or staff from universities is also a useful indicator regarding certain aspects of U-IRC. While joint research, with business sector co-funding, covers mostly the case of collaboration with medium and large companies, startup formation focusses on the small business side of the interaction.

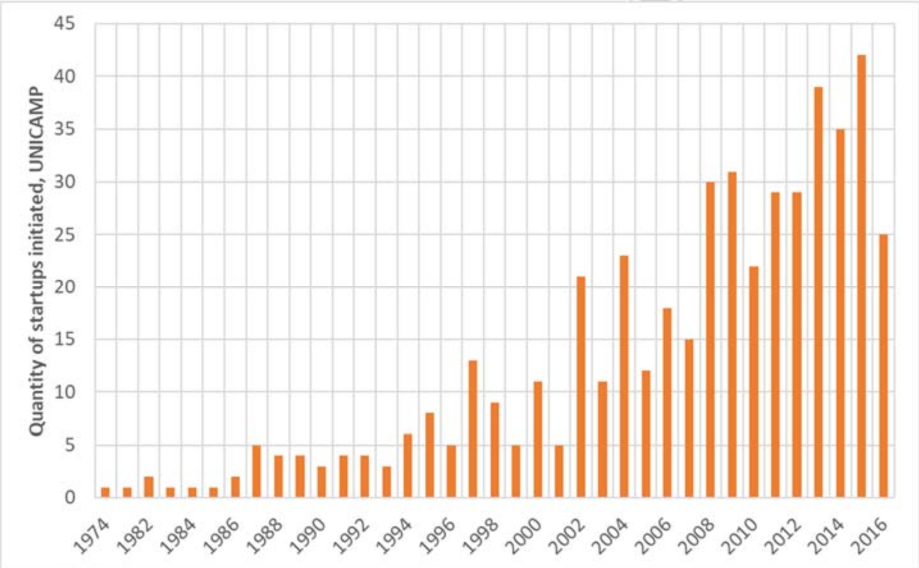

Figure 11. Quantity of startups initiated by students and faculty from Unicamp, by year.

In Brazil, few universities have a database of startups that have originated from the university. The most complete database is that of the State University of Campinas (Unicamp)[23] from which the data in Figure 11, displays the number of startups created yearly, since 1974.

[22] INPI, "Principais Titulares de Pedidos de Patente no Brasil, com Prioridade Brasileira Depositados no Período de 2004 a 2008", julho 2011. http://www.inpi.gov.br/menu-servicos/informacao/arquivos/principais_titulares_julho_2011.pdf

[23] https://docs.google.com/forms/d/e/1FAIpQLSepaQDACAOMhCetBEIgxiUYdhv_3jCYPrExZbcaoXJ1fAj8YQ/closedform

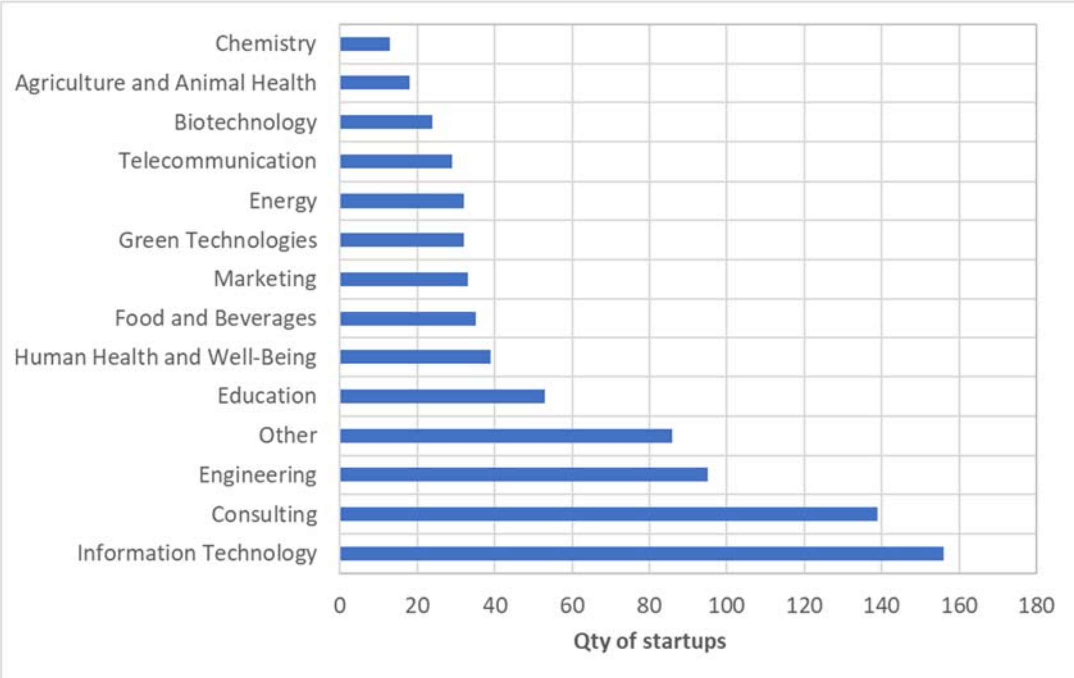

Figure 12. Unicamp's startups by sector. (Source: Agência de Inovação da Unicamp, 2017)

Figure 12 shows the distribution of those startups across industry sectors, demonstrating a dominance in IT and Engineering.

Each year the university surveys the companies in its database establishing for example that, in 2016:

a) The companies originating from Unicamp sustained 28,000 jobs.

b) The companies' revenues were R$ 3 billion.

c) 26% of the surveyed companies had an office abroad.

A comparison of the data from Unicamp with that for universities in the USA is shown in Figure 13, using data from the AUTM database. The figure correlates the number of startups generated in a given year with the R&D expenditures at the university in the same year. This does not mean that all startups arise from research performed in the same year, the value spent in R&D is used in the figure as a proxy of the vitality and breadth of the academic environment in each organization.

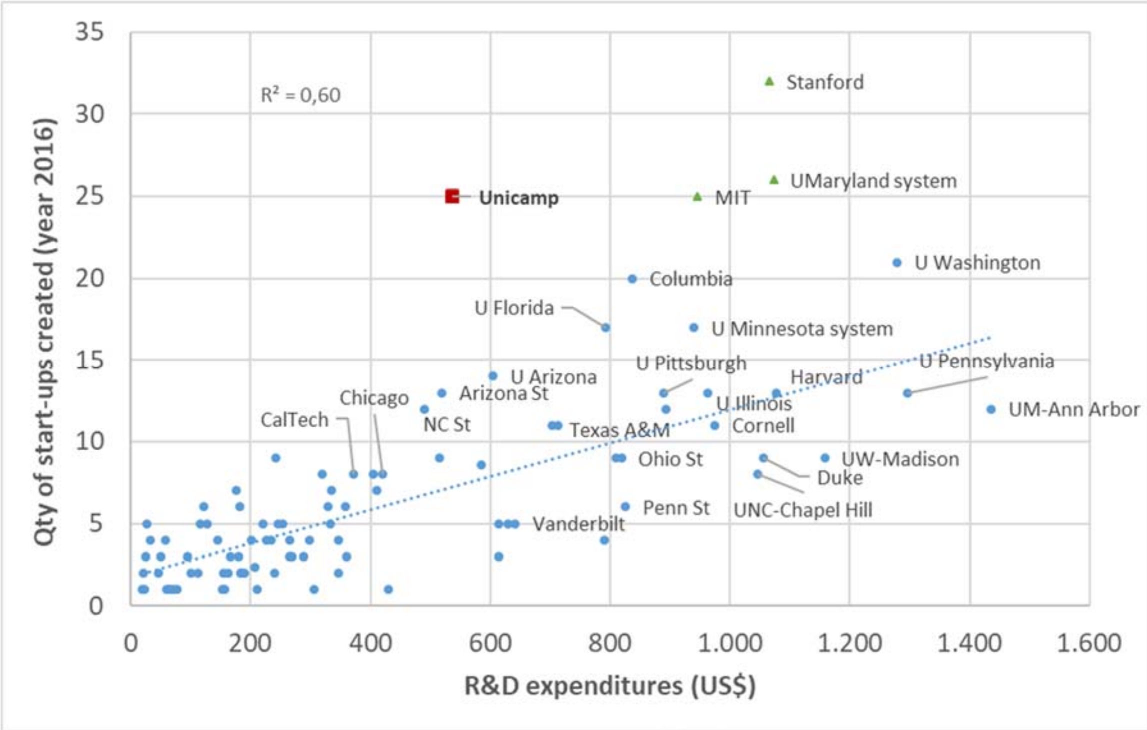

Figure 13. Quantity of start-ups created plotted against the university's R&D expenditures. Base year is 2016. (Source: AUTM database and Unicamp's Statistical Yearbook).

Interestingly, Unicamp fares quite well in the comparison about the quantity of startups generated. The performance of Unicamp may be boosted by the fact that in Brazil universities do not, so far, require title or royalties from student-/professor-initiated companies. Still, in other aspects, such as the growth of each of these startups in time the results, though reasonable as described above, are not yet as remarkable as seen in universities in the USA. Part of the issue might be related to the weakness of the venture capital environment in Brazil. A single number illustrates the disparity: in 2017 the VC market in the USA mobilized more than US$ 70 billion[24] compared to Brazil at R$ 8,3 billion[25].

6 Conclusion

This paper outlines indicators that might be helpful to assess the evolution of U-IRC in Brazil, and the effectiveness of public policy instruments created to facilitate and foster U-IRC. Each indicator is presented with data obtained for universities in Brazil and in the U.S. Indicators beyond those exemplified here should also be considered. The illustrations aim mostly at demonstrating that it is possible to determine the indicators and benchmark them. Additionally, the indicators discussed here show that there are certain parts of the S&T system in Brazil for which U-IRC is much more than "incipient" but is well established and increasing over time.

[24] PwC and CB Insights, Money Tree Report Q4, 2017. P. 76. https://gcase.files.wordpress.com/2018/01/cb-insights-moneytree-q4-2017.pdf

[25]KPMG and ABVCAP, "Consolidação de Dados, Indústria de Private Equity e Venture Capital no Brasil 2018", available at https://assets.kpmg.com/content/dam/kpmg/br/pdf/2018/06/br-kpmg-consolidacao-de-dados-pevc-2018.pdf

The data shown here points to important hurdles to be considered. For example:

a) There is a large fraction of co-authoring companies which are not Brazilian and do not even have any R&D in Brazil. This suggests that many universities in Brazil have state of the art, internationally competitive research capacity, that attracts the interest of these partners. At the same time, few Brazilian companies use this asset. Other chapters in this publication deal with the reasons for this, but it suffices to say that the protected economy strategy which has dominated the Brazilian economic policy for decades cuts-off many Brazilian companies from global value chains and decreases their capability or interest in advanced innovative R&D

b) The size of the business sector R&D enterprise in Brazil is small when compared to that of developed countries. As a reference, consider the data mentioned in section 3.1: the business sector in Brazil employs 1/16 of the number of researchers employed by the business sector in the U.S. This limits the interaction of business with universities, due to a limited absorptive capacity affected by the quantity of potential interacting persons from the business sector.

c) The harm done to Petrobras by policies enacted until 2015 reduced the effectiveness of one of the important instruments for developing tech-based companies, particularly suppliers in the oil-sector. Together with the economic troubles that resulted in the overarching present economic difficulties in the country, the capability of the government and that of the private sector to invest in R&D was seriously damaged.

d) In most universities, still, the role of developing business sector partnerships is dealt with in an amateurish way. Institutional support for researchers to develop the collaborations is weak in most cases. This leads the scientists themselves to try and work on the contracting and juridical issues necessary for contracting which is a bad choice, as experienced professionals could speed up the negotiations. This lack of expertise causes an excessive focus, in the national debate, on "excessive bureaucracy" and the like. Contracting, in any case, and especially when it must protect the public interest requires some bureaucracy, and the matter must be dealt with by professionals, and not by scientists who should be doing research and supervising students. Universities which have professional support are forging ahead rather well and using the available opportunities.

The use of adequate indicators can stimulate the organizations that are part of the S&T system to consider them in their initiatives. This tends to foster the continuity of the initiatives and allows for criticism and suggestions for improvement that may come from the academic and business research communities. It will also inform the national debate, leading to higher quality proposals of policies to be enacted. Evidence based policy might help the policy makers to act in a more effective way than traditional practice of "anecdotal" based policy that is so frequent in the debate in Brazil. Targets could be set, the indicators tracked, and the policy adjusted to obtain the stated objectives.

What Brazil cannot afford anymore is not to use any indicator to assess this important part of its S&T policy.