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SOCIAL SCIENCES

Innovation in Brazil: Universities, Embraer and Petrobras

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Abstract: Innovation affects a nation's sovereignty. In this paper, we look at Science and Technology indicators as proxies for Innovation using databases such as WIPO, INPI, Sucupira and Scival, and including patents registered, academic-corporate collaborations, patents citing Brazilian articles (Number of patents and documents) and technical production in Brazilian higher education institutions. We also look at two major previously state-owned companies (Embraer and Petrobras) to see their patenting and citation behaviour compared to other companies worldwide. Brazilian science is a citation basis for patenting in companies and universities worldwide, but Brazil does not use its own publications to support patent proposals. While USP is the major cited university, Unicamp has more patents. Academic-corporate collaboration exists between Brazilian and foreign universities, especially in the US and Europe. The Brazilian companies show low patenting behaviour, but Embraer has a higher impact than Petrobras. As a consequence of the dynamics of science and technology, we suggest that the analyses of the innovation processes could focus on the generation of startups and, in particular, academic spin-offs.

Key words: citation, impact, patents, scientometrics.

INTRODUCTION

Research quality and impact measurement has become an essential branch of science (Scientometrics) in recent years (Mingers & Leydesdorff 2015). This includes fields such as bibliometrics, informetrics, webometrics and altmetrics. These authors highlight that these studies have been based mainly on citation measures, largely ignoring other actions involved in the quality of research by an individual, institution, knowledge area or country. There are a large number of studies comparing databases such as SciVal (Elsevier) or InCites (Clarivate Analytics) in terms of their use and coverage as a measure of research quality (Ruas et al. 2017). Still, few studies look at their adequacy to measure the impact of an institution or area of knowledge. McManus et al. (2021) found that scientific papers from business had a higher impact and prominence than academic papers and were cited more often in patents.

Citing-cited patent activities are a critical source of emerging new patents (Oh et al. 2017), and patent citation reveals the diffusion of information and its applicability into many other technical fields, which gives birth to new technology (Sharma & Tripathi 2017). Maggioni & Uberti (2011) state that innovative activity, organisation, especially firms, or territory of an agent can be analysed through patents because they reflect marketable information of innovative technology and, therefore, are a representative proxy for a technology (Trajtenberg et al. 1997). Nevertheless, Wartburg et al. (2005) state that single-stage citation analysis cannot reveal technological paths or lineages, while Tijssen & Winnink (2018) question the validity of metrics and quantitative indicators such as citation analysis used to measure excellence in Research, Development and Innovation (RD&I). Comparative measurement and large-scale benchmarking can only go so far, as in-depth understanding requires information from supporting case studies.

The development of a nation depends on the production sector, and Brazil's is primarily based on commodities such as petroleum and gas, agriculture and some innovative technologies[1]. Brazil is classified as an Upper middle-income country, performing above expectations for the level of development in the 2021 WIPO report[2]. It is currently ranked 57th in the Global Innovation Index rankings. The WIPO report states that Brazil is lagging in infrastructure (69th) and market sophistication (75th) and ranks 78th in institutions, 48th in Human Capital and research, business sophistication (34th), knowledge and technology outputs (51st) and creative outputs (66th). This indicates that many changes are needed for Brazil to improve its ratings. Vasconcelos & Silva (2019) discuss intellectual property rights (IPR) in Brazil and their effect on Innovation. They show that IP indicators in patent registration, industrial designs and technology contracts have declined. With the companies' internationalisation, market strategies increasingly require the insertion of new technologies in their products and processes, making patents an essential factor among the different industrial segments, having a positive impact on the process of economic growth and technological progress of the countries in the international world trade (Cavalheiro et al. 2016).

Major companies involved in this sector are Petrobras and Embraer (Empresa Brasileira de Aeronáutica/Brazilian Corporation for Aeronautics). Both were State Owned Enterprises (SOEs), with the Brazilian government owning 64% of Petrobras. Embraer was privatised in 1994, but the Brazilian government retains veto power**.** At present these two companies account for 87% of scientific papers published in the Web of Science and 58% in Scopus by the corporate sector in Brazil.

The quality of Innovation is based on the quality of science. Therefore, using the scientometric databases and taking this as the premise, we look at Brazilian universities and these Brazilian companies using international databases and question whether their use is adequate to measure scientific quality. While using patent citations and citing patents can be examined (Kuhn et al. 2020), studies have shown Petruzelli et al. (2015) that science-based patents are sources for the assignee's subsequent inventive process, and patents with a broader scope influence non-industry-specific patents. Chen (2017) shows that patent citations can indicate knowledge linkage. Results vary by area of knowledge (Gazni 2020). According to Iizuka & Hollanders (2017), innovation indicators include those for Science and Technology (S&T), survey and composite combining the abovementioned indicators. The current paper is based on the first set (S&T) of indicators. Although indirect, they indicate factors closely associated with the innovation process based on shared understandings. These include patents, research cited by and citing patents, academic-corporate publishing and its impact.

1 https://oec.world/en/profile/country/bra/

2 https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021.pdf

MATERIALS AND METHODS

Information was collected on registered Brazilian innovation (from all sources – universities and companies) through different databases. Data from 2012 to 2021 was collected using online databases, including WIPO[3] (World Intellectual Property Office), including Global Brand Database, Global Design Database and PCT (Patent Cooperation Treaty), INPI[4] (National Institute of Industrial Property - Instituto Nacional da Propriedade Industrial), as well as publication databases such as Scival (Elsevier) and InCites (Clarivate Analytics). Scival also indicates patent offices and research topics studied by companies. In WIPO we looked at International Registration of Appellations of Origin (AOs), Geographical Indications (GIs), The International Microorganism Deposit System, Global Brand and PCT Databases, as well as looking at patent classifications.

Further data was collected from the Sucupira[5] database with information on technical products from postgraduate courses in Brazil (where 95% of scientific production occurs), namely Apps, Patents, and research reports where private companies are significant funders, from 2012 to 2020.

Major Brazilian companies were identified[6], with four companies are responsible for about 80% of publications in the sector in Brazil (Petrobras, Embraer, CPQD and Fleury). Publications and patents from two Brazilian private but previously state-owned companies/institutions (Petrobras and Embraer) were further evaluated. The two other companies listed were not included: CPQD (Centro de Pesquisa e Desenvolvimento em Telecommunicações - Research and Development Center in Telecommunications and IT) and Fleury, a company involved in clinical exams. CPQD published more than 70% in congresses, and Fleury published almost entirely in collaboration with national universities so their data were captured in the university analysis. Other Brazilian companies did not appear strongly (<20 papers/year) in the citation databases (WEG, CESAR, several governmental and private banks, Vale SA, Braskem, JBS, Copel) and were also not included in this analysis. This does not mean they do not innovate.

Petrobras and Embraer were compared with similar companies and research institutions in other countries (Table I) where data were available.

Data for these companies included annual revenue (from company homepages), number of papers published, field (FWCI) and normalised (CNCI) citation impact indices, international collaboration (%), number of patents, cited patent count, media exposure and impact, and academic-corporate (business) collaboration

Table I. Companies and Research Institutions Compared.

Petrobras	Embraer
Shell	Boeing Business Jets
Total	Rolls Royce
BP plc	Dassault Falcon
Equinor ASA[1]	Rayethon
ExxonMobil	Bombardier Aerospace
Saudi Aramco	Airbus Corporate Jets
Chevron	Textron Aviation
Lukoil	SAAb AB
Sinopec	Northrop
China National Offshore Oil Corp	Lockheed Martin
Rosneft	
PetroChina	

[1]**Formerly StatOil.**

3 https://www.wipo.int/portal/en/index.html

4 https://www.gov.br/inpi/pt-br

5 https://sucupira.capes.gov.br/sucupira/

6 https://companiesmarketcap.com/brazil/largest-companies-in-brazil-by-market-cap/

and impact. FWCI and CNCI are calculated based on one (1) as the world mean by area of knowledge, by taking into account different citation patterns. Therefore, they represent the ratio of the actual number of citations received by a document and the "expected" number for a document with similar characteristics.

Regressions of annual revenue on patent count were created and patent citations over time. Clusters of companies were formed within each area of knowledge (Oil & Gas/Aeronautics) based on all indicators and patent citations. Data were analysed using SAS® (Statistical Analysis System Inc, Cary, North Carolina). Published papers by these companies from 2012 to 2021 was also collected from Scopus and network analyses performed in Vosviewer.

RESULTS

Brazilian information in WIPO (World Intellectual Property Organization)

No information was registered for Brazil in the International Registration of Appellations of Origin (AOs), Geographical Indications (GIs), or The International Microorganism Deposit System. Brazil had no indications in the Global Brand Database in the Designated Contracting Party or as Applicants Contracting Party. In the Holder section, there were 5,515 registers for Brazil, of which 2,245 were active, 38 were pending, and 2,389 were inactive. Brazil has no Global Brands but acts as a Holder Country and Designating Contracting Party for 56,099 and 32,085, respectively. In the PCT Database, Brazil has 23,120 registers, with 11,912 since 2012 (Table II). HP, Whirlpool and Petrobras are major companies, with Unicamp registering most among Brazilian universities. Most patents from Whirlpool were registered by EMBRACO (Brazilian Compressor Industry), a Brazilian company founded in 1971 that from 2006 on became Whirlpool SA (a subsidiary of Whirlpool Corporation) and in 2019 was sold to the Japanese company NIDEC.

Compounds registered are mainly in the biochemical and medical areas (Supplementary Material - Table SI, Figure S1), with A61K – medical, dental or toilet purposes being the most evident. These involve detection,

Table II. Number of Brazilian patents by patent office and company.

Patent Office	All	Since 2012	Company	All	Since 2012
PCT	20,729	10,324	Hewlett Packard Development Company LP	312	254
Singapore	1,301	1,269	Whirlpool SA	310	164
Japan	459	89	PETROBRAS SA	240	177
South Africa	341		UNICAMP	204	155
Canada	222	198	BASF SE	148	
Brazil	49	36	Dow Global Tech LLC	141	126
Australia	7	3	Braskem SA	140	115
USA	4	2	Unilever NV	135	
Costa Rica	1	1	Unilever PLC	135	
Germany	1		UFMG	130	87
Spain		1	L'OREAL		110
Indonesia		1	Mahle International GMBH		109
All	23120	11912	Mahle Metal Leve S/A		89

PCT – Patent Cooperation Treaty; Unicamp – Universidade Estadual de Campinas; UFMG – Universidade Federal de Minas Gerais.

treatments, use (*verwendung*) and procedures (*verfahren*) for diseases such as cancer. Patents in the areas of C07C (Acyclic or Carbocyclic Compounds (macromolecular compounds; production of organic compounds by electrolysis or electrophoresis) and A01N (Preservation of bodies of humans or animals or plants or parts thereof (preservation of food or foodstuff) and Biocides) have decreased since 2012, while A61Q (specific use of cosmetics or similar toilet preparations) and E21B (Earth or rock drilling (mining, quarrying e21c; making shafts, driving galleries or tunnels e21d); obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells) have become more prevalent.

In the INPI (Instituto Nacional de Propriedade Industrial) database, there are 68 geographic indications with known precedence (mainly foods such as wine or cachaça, meat, coffee, fruits, cheese, chocolate, shoes, and handcrafts), 32 Designations of Origin (again dominated by foodstuffs). There were also 362 Computer Programs and 912 Industrial Designs. There were 40,397 processes in the INPI patent database.

Brazilian Publications

Brazil produced 16,517 publications with Academic-corporate collaboration (Table III) during the period (SciVal). These received 37 citations per publication and had a FWCI of 3.27, compared with 0.90 for all publications and 1.54 for international collaboration. Natural Sciences dominated Academic-corporate collaboration, followed by Engineering & Technology and medical. Nevertheless, Medical and Engineering had more patent citations per output. A low percentage of Social Sciences and Humanities publications were in collaboration with corporations. In all areas, collaboration increased FWCI.

Over the years, academic-corporate collaboration increased linearly (Figure 1a), and patent citations of these papers increased exponentially (Figure 1b).

The USA has the highest use of Brazilian papers (Figure 2) in patents. USP and Petrobras have the highest number of publications in patents, mainly in super-journals such as PlosOne or Scientific Reports and specialist journals such as in Medicine, physics and engineering. International collaborations are important, as some of the major Brazilian academic-corporate collaboration shows triangulation, such as those with CNRS (France), Harvard (USA) and other universities in several countries (Heidelberg, Paris, Helsinki, Lund, etc).

Table III. Scholarly Output in Brazil with both academic and corporate author affiliations by knowledge area.

	Number	Cit/pub	FWCI	%	Citing Patents[1]	Patent-Cited[2]	Patent citations /output[3]
Overall	16517	37.0	3.27	2.1	17552	6198	27.0
Agriculture	1729	16.1	1.45	1.3	1567	641	14.0
Eng & Tech	5560	11.8	1.11	3.5	5008	1693	33.9
Hum	65	18.0	2.40	0.3	23	11	1.0
Med	4880	72.2	7.0	1.7	9600	3251	40.7
Nat	11660	23.8	1.84	2.6	11283	3971	29.1
Social	744	22.3	2.05	0.7	396	134	3.9

[1] count of patents citing the Scholarly Output published in Brazil; [2] count of Scholarly Outputs in Brazil that have been cited in patents; [3] average Patent-Citations received per 1,000 Scholarly Outputs published in Brazil.

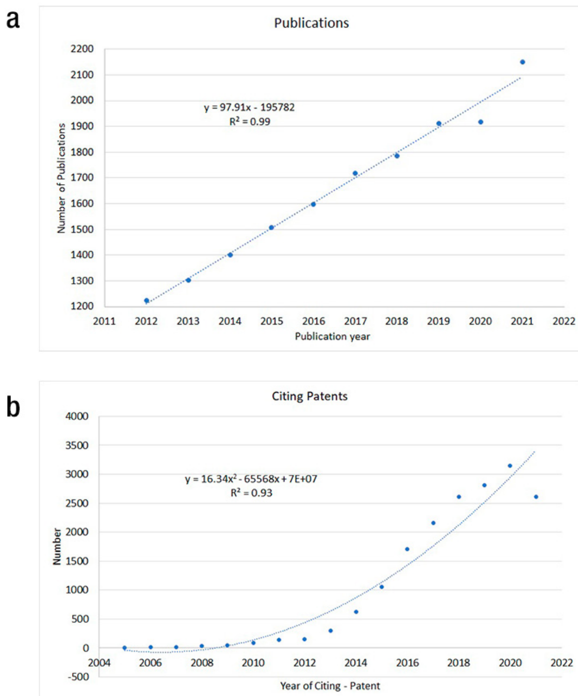

Figure 1. **Brazilian publications in Academic – Corporate collaboration (a) and their citations in patents (b).**

Patent Citations

From 2012 to 2021, 17,552 patents cited 6,198 scholarly outputs published in Brazil (Figure 3). There were 21,479 patent citations received, averaging 27 per scholarly output. The major citing countries were USA, UK and Germany. Universities such as the University of California, MIT, and Duke cite Brazilian papers in their patents and private companies such as AT&T and CPG.

When looking by area of knowledge (Figure 4), the USA and Europe are major citing countries. Argentina is seen in natural and medical sciences and the UK in Social Sciences.

USPTO (United States Patent and Trademark Office) and WIPO are the top offices with patents citing Brazilian literature (Table SII) with 6572 and 5387 respectively, followed by the European Patent Office with 3644.

Citing applicants are mainly private companies and universities (Table IV) in all areas of knowledge (>90%). Private companies have over double the patents of universities. The Brazilian institutions cited in patents are USP and Unicamp and include foreign institutions such as CNRS, Harvard, Inserm and CSIC. USP is the leader in all areas, especially Medicine. As seen with citing sources, publication sources are either super-journals or area specific, with few Brazilian journals cited.

Most of the papers cited in patents (Table V) were open access (especially green). Nevertheless, the difference between open and non-open access was small.

Other Production

Data from the postgraduate network from 2013 to 2020 (Table VI) and their word clouds in Figure 10 show a comprehensive production of technical products, totaling 65,860 in 8 years. These included apps for computers, products, patent applications, and techniques.

The emphasis on education and health matters are dominant, as well as management and control (Figure 5).

Brazilian companies

Petrobras was responsible for 56.3% of publications in Scopus by Brazilian companies and Embraer 6%. While Brazilian companies tend to publish a high percentage of papers in the top 10% of journals, the citation rates were significantly lower (Table VII). This is especially evident for Embraer, which also has no cited patents.

The predominant themes researched are similar to world themes (Figure 6), showing that research in these companies is aligned with major companies worldwide.

Major collaborators for all four companies tend to be Brazilian universities (Table VIII), but

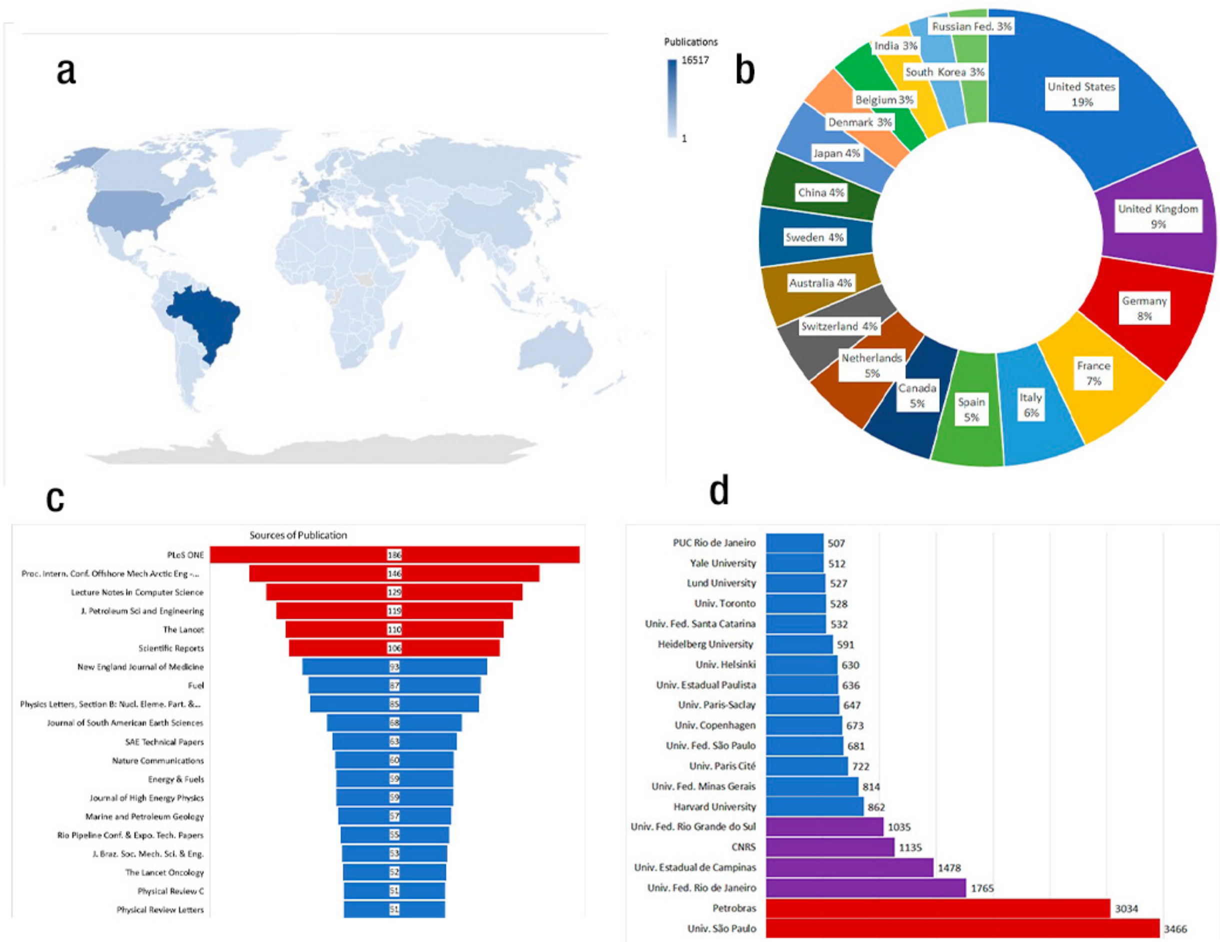

Figure 2. Publications in Brazil with author(s) with both academic and corporate affiliation: a) Country affiliation (except Brazil, > 1000 publications); b) Top Countries citing Brazilian papers; c) Sources and d) Institutions cited in patents.

the impact of these collaborations varies. For Petrobras, institutions other than UFRJ show higher impact such as UFRGS and Unicamp, with UFES the only one with an impact greater than the world mean. Embraer impact is higher than the world mean, and collaboration with international companies improved this. The collaboration with international institutions tended to lower the impact, except with ITA.

Embraer's impact aligned with the world average, while Petrobras's was relatively low (Table SIII). Lower rates of international collaboration accompanied the lower impact. While most companies showed a higher impact with academic-corporative collaboration, this was not the case with Petrobras (see Tables SIII and SIV and Figure 7).

The Brazilian companies (Figure 7) tend to show a low rate of patent registration compared to their revenue or budget, as all fall below the mean tendency line. Petrobras shows a patenting profile similar to Russian companies such as Lukoil, Rosneft, or Equinor (formerly Statoil). In the case of Embraer, few patents are registered, similar to Rayethon.

The Federal University of Rio de Janeiro (UFRJ) is Petrobras's major collaborator, mainly through its COPE (Instituto Alberto Luiz Coimbra

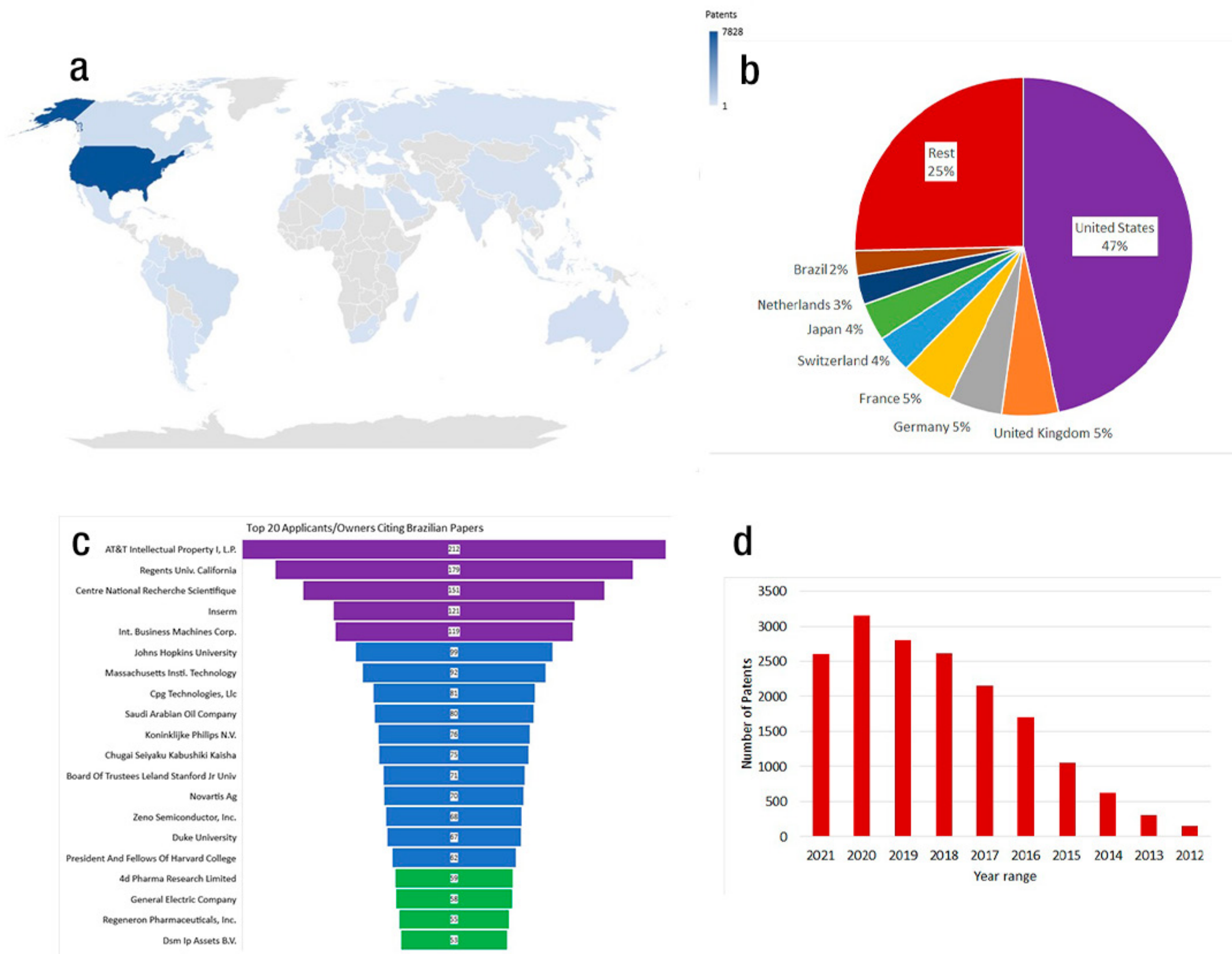

Figure 3. a) Distribution of citing Countries; b) Major citing countries; c) Top 20 applicants/Owners and d) year of publication.

de Pós-Graduação e Pesquisa em Engenharia) division (Table IX). Results show that papers published by Petrobras or in conjunction with UFRJ tend to have a lower impact than papers published by other universities, depending on the field of knowledge.

Looking at clusters (Figure S2), only Embraer shows RD&I impact in line with major companies. As seen in Figure S3a, the collaboration of Petrobras with universities in Brazil and abroad is less than optimum. While other companies tend to collaborate more with institutions with a higher impact on scientific output, Petrobras does not follow the same model. Its top collaborators do not differ from the mean impact. This may be several-fold, but one reason may be the lack of open calls and competition for these research grants. There is no clear frontier between the federal government and Petrobras (Ribeiro & Furtado 2015), so political actions often precede technical ones (Tõnurist & Karo 2016). Gay (2014) argued that its innovation strengths are not presented through patent statistics but through applied engineering skills for domestic development and the customisation of oil industry technologies. Nevertheless, Brazilian companies publish in the same fields as their international counterparts, but their research shows a lower citation impact. This may have several reasons. While their major collaborator

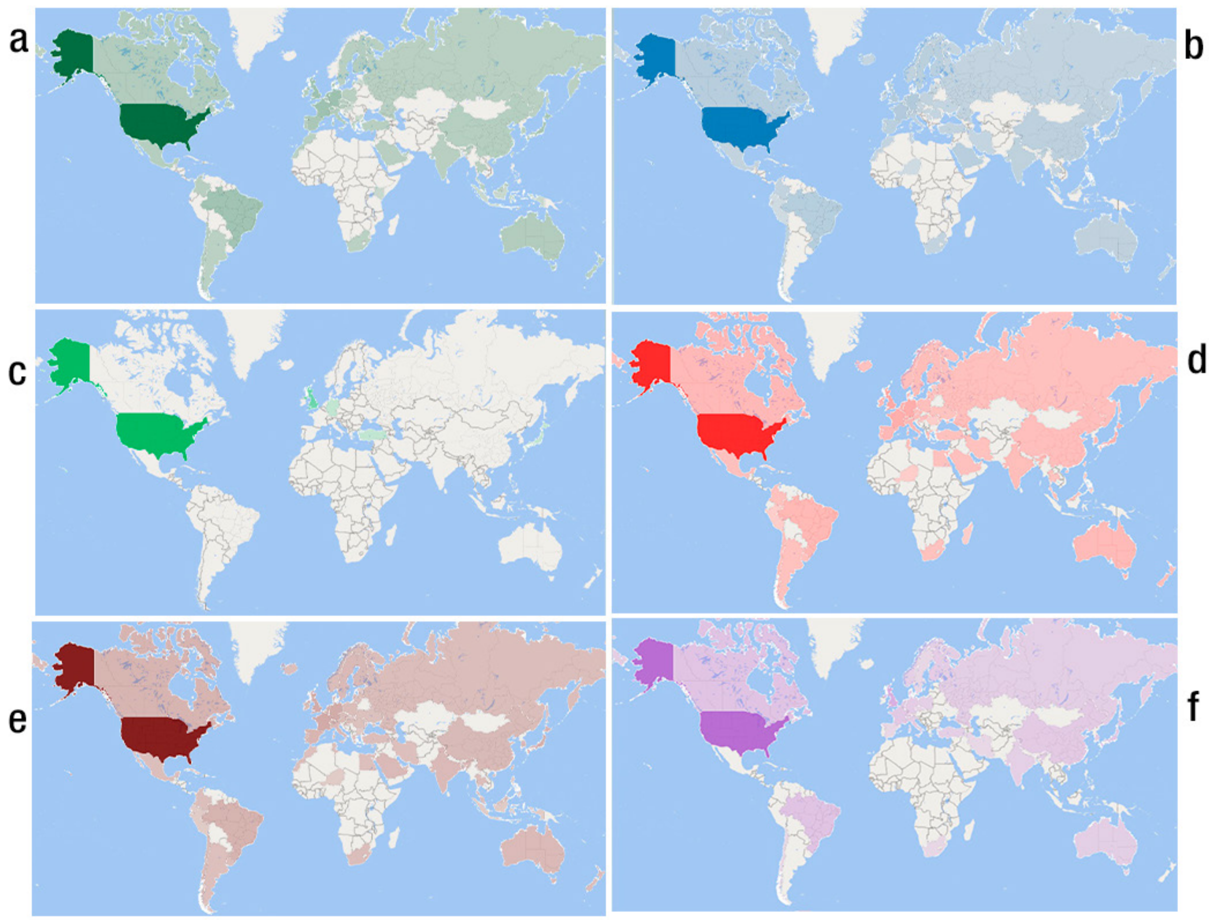

Figure 4. Heat maps for Patent country citing Brazilian authors by area of knowledge a) Agriculture; b) Engineering & Technology; c) Humanities; d) Medical Sci; e) Natural Science and f) Social Sciences.

in Brazil is the Federal University of Rio de Janeiro, this collaboration has almost always had a lower impact than other universities in the country and abroad (Table SIII).

In the case of foreign collaboration, where Petrobras collaborates with the same universities as other major oil companies (Table SV), the impact of the science produced is almost always of low impact (taking one as the world mean in the specific field of knowledge) and of lower quality than that produced by the other companies. Petrobras collaborates significantly more in Engineering and Material Science than other companies and substantially less in Earth and Planetary Sciences (Fig. S2). The impact of the papers produced by Petrobras is lowest for all companies in all areas of knowledge examined (Fig. S2c), and only in Earth & Planetary Sciences is it greater than 1 (the world mean), while most other companies are above 1 in all areas.

The network analysis (Figure 8) shows poor institutional network construction with these companies. Most collaborations are with Brazilian institutions and researchers, but these tend not to form solid networks but instead rely on individual collaborations.

Table IV. Citing applicants for papers by Brazilian authors worldwide in Patents based on the top 100 applicants by area of knowledge Top 20 publishing institutions with Brazilian authors and Top 20 Publishing Sources.

	Agriculture	Engineering & Technology	Humanities	Medicine	Natural	Social	Total
Applications							
Government	28	29		116	136	10	319
Personal	30	52	5			31	118
Philanthropic				44	18	2	64
Private	487	1408	17	1359	1930	219	5420
University	107	286	2	1213	1032	72	2712
Total	652	1775	24	2732	3116	334	8633
Publishing Institution							
USP	164	346	3	929	929	38	2409
Unicamp	82	211		219	409	9	930
UFRJ	36	117	2	251	355	6	767
UFMG	34	87		277	275	16	689
UNESP	66	112		191	265	5	639
UFRGS	37	110		226	239	9	621
UNIFESP	15	38	1	265	142	7	468
FIOCRUZ	24	29	1	224	175	2	455
UFSC	21	91	1	95	144	5	357
EMBRAPA	79	62		53	144	2	340
CNRS	9	63		99	160	1	332
Harvard University	4	12		209	87	3	315
UFPR	21	58	2	71	115	7	274
UFSC	15	80	1	42	124	3	265
UnB	9	45		72	106	4	236
UFC	18	47		66	82	5	218
UFSM	21	29		67	80	4	201
INSERM		7		111	74		192
CSIC	8	36		52	75	1	172
UFF	9	25		54	79		167
Source							
PLoS ONE	80				80		160
Molecules				38	38		76
Carbohydrate Polymers		33			33		66
New England Journal of Medicine				60			60
Vaccine	20			20	20		60
Materials Research		29			29		58
BioMed Research International		18		18	18		54
Food Chemistry	27				27		54
Applied Microbiology and Biotechnology		17		17	17		51
European Journal of Medicinal Chemistry				22	22		44
Fuel		21			21		42
Inter. Journal of Molecular Sciences		21			21		42
Bioresource Technology		20			20		40
Brazilian Journal of Microbiology				19	19		38
Biotechnology for Biofuels	9			9	9	9	36
Process Biochemistry	12			12	12		36
Food Research International	34						34
Frontiers in Immunology				17	17		34
Journal of the Brazilian Chemical Society					34		34
The Lancet				34			34

Table V. Type of publishing for patent – citations.

Type of Publ	Agr	Eng	Hum	Med	Natural	SS	Total
All Open Access	368	589	5	2043	1990	60	5055
Bronze	101	127	1	586	530	18	1363
Gold	179	228	1	756	778	21	1963
Green	280	474	3	1710	1634	42	4143
Hybrid gold	23	29	1	222	166	3	444
Not Open Access	273	1104	6	1208	1981	74	4646
Total	**1224**	**2551**	**17**	**6525**	**7079**	**218**	**17614**

SS- Social Sciences.

Table VI. Type of technical products declared by postgraduate courses in Brazil (2013-2020) on the Sucupira platform.

Type	Subtype	Sub-total	Total
Apps	Computer	10955	13451
	Multimedia	1276	
	Other	1220	
Products	Apparatus	332	17233
	Equipment	2007	
	Pharmaceutical	3360	
	Instrument	5715	
	Other	5819	
Patents			24375
Techniques	Analytical	2255	10801
	Instrumental	1113	
	Other	1417	
	Pedagogical	2681	
	Procedural	2764	
	Therapeutic	571	
Total			65860

DISCUSSION

The question of sovereignty in science is essential in constructing national identities (Strasser 2009), with a strong correlation between the quality of science produced in a country and that country's development (Meyer et al. 2010). Figueredo (2014) described innovation activities, including patenting and Research & Development, as key to the process and correlated with expenditure (Griliches 1990). Patent citations are also used to indicate patent quality (Guan & Gao 2009, Hu et al. 2012). Hsu et al. (2021) showed that companies' basic knowledge of technological advances comes from scientific journals and publications that can affect their commercial value (Arora et al. 2018). In light of the results presented here, these point to a lack of innovation quantity and quality in Brazilian firms.

Brazil, like other countries, uses several methods to stimulate RD&I. These include tax incentives, for example, Lei do Bem 11.196/2005 (Brasil 2005); Law 11.774/2008 (Brasil 2008); Informatics Law 13.674/2018 (Brasil 2018a); Innovation Law 10.973/2004 (Brasil 2004) and Regulatory Framework for Innovation (Brasil 2016a). Indirect support for science and technology from the State comes from subsidies

Figure 5. WordClouds for a) Apps, b) Technical Products; c) Products and d) patents from Sucupira database.

in the form of low-interest loans such as BNDES shares (Cirani et al. 2016), credit guarantees, equity investment programs, and venture capital programs. The innovation discourse is exaggerated at the expense of a balanced view of the necessary relationship between investments in basic and applied research and Innovation (Arbix et al. 2017). Successive plans such as the National CT&I Plan (PNCTI), Industrial, Technological and Foreign Trade Policy (PITCE), Brasil Maior Plan (PBM), and National Knowledge Platforms Program (PNPC) lack a clear definition of instruments, resources and governance for implementation, as well as continuity (Baeta Neves et al. 2020). A bigger problem is the inability to set priorities. According to Arbix et al. (2017), when many sectors are chosen as a priority, the ability of public agencies to react is diluted, and too many priorities are the same as none.

Several instruments and programs supporting RD&I in Brazil are hampered by the lack of continuity of the allocated resources. Additionally, most of these instruments and programs are driven much more by supply than demand. This second aspect is associated with the difficulty of establishing priorities, as pointed out earlier. Fostering demand-driven RD&I also allows innovation policies to be focused on solving structural problems such as sanitation, housing, etc., and developing strategic areas such as bioeconomy, renewable energy, water security, etc. Existing instruments that use the State's purchasing power, such as public contracts for innovative solutions, competitive dialogues, and competitions for Innovation, among others, represent effective partnerships between government and companies to foster Innovation. These instruments are widely used in more innovative countries and need to be used more in Brazil.

Oil companies' obligation to invest in RD&I is part of a specific contract clause for exploration, development and production. The RD&I clause establishes the application of a percentage of the gross revenue from production depending on each type of contract. The National Agency regulates this for Petroleum, Gas, and Biofuels (ANP). Mancini & Paz (2018) show that it had a minor impact on fostering the relations between oil and service companies, and technology-based

Table VII. **Basic data on Brazilian companies in this study (2012-2021).**

	Petrobras	**Embraer**
Area	Oil and Gas	Aviation
Annual Revenue (USD 2019)	90.1b	5.7b
FWCI[1] (2012-2021)	0.80	1.09
CNCI[2]	0.70	1.07
Papers	4117	264
Authors	3332	247
Citations/p publication	8.3	7.5
h5	32	17
Pub. 10% most cited	7.9	11.4
Pub. Top 10% journals	25.9	21.7
Academic-Corporate	74.8	81.1
Citing-Patents Count[3]	152	6
Patent citations per output[5]	198	2
Patent Citation output[4]	48.1	12.9

[1]Field Weighted Citation Impact (SciVal®); [2]Category Normalised Citation Impact (Incites®); [3] count of Scholarly Outputs that have been cited in patents; [4] count of Patent-Citations received; [5] average Patent-Citations received per 1,000 Scholarly Outputs.

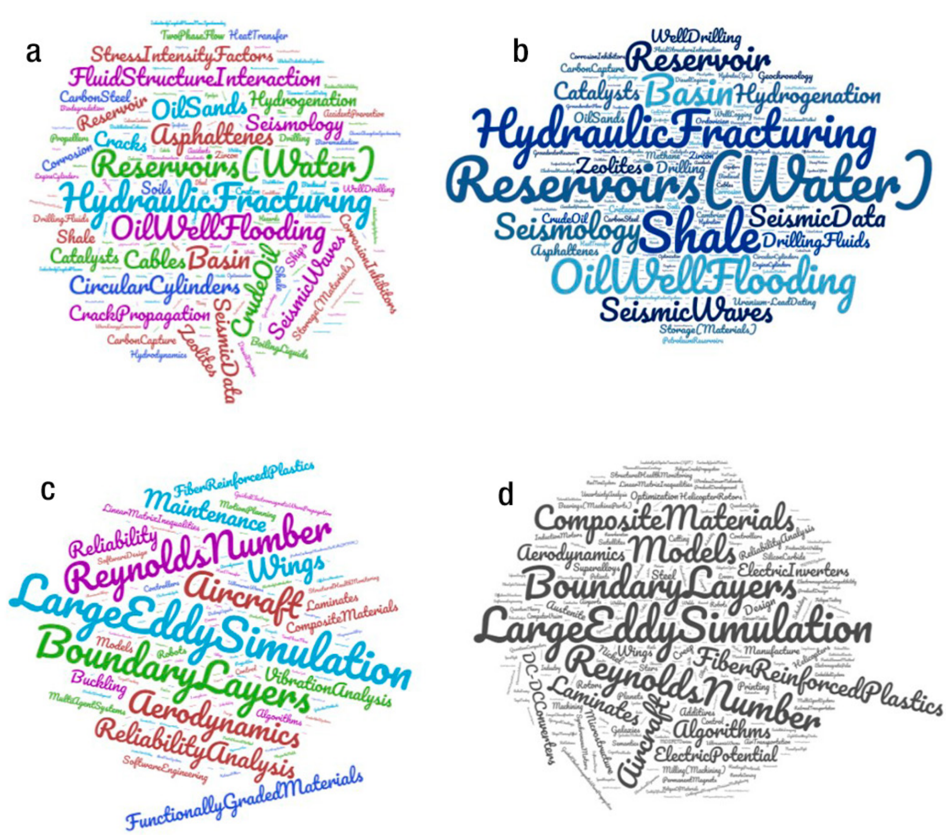

Figure 6. **Word clouds for most common themes researched in selected Brazilian companies and worldwide in their area of knowledge (Scival).**

firms have played only a minor role. The same authors stated that Petrobras invested most of what it was not compelled to transfer to the STOs (Science and Technology Organizations) into its research Centre (CENPES), different from other companies, which may explain, in part, their low impact. Although more than 70 STOs were involved in the Thematic Network (De Negri & Squeff 2016), most went to UFRJ (Mancini & Paz 2018).

Table VIII. Major Brazilian collaborators and impact (FWCI) with Embraer and Petrobras.

Petrobras		Embraer	
UFRJ	0.76	ITA	1.01
PUCRJ	0.72	USP	0.85
USP	0.71	IAE	0.63
Unicamp	0.83	Univ. of Bristol	2.65
UFF	0.68	German Aerospace	1.80
UFRGS	0.89	UFSC	0.82
UERJ	0.66	INPE	0.69
UFSC	0.86	UNIFESP	0.70
CEFET-CSF	0.85	Univ. of Lisbon	2.54
UFES	1.05	UNESP	0.76

a

b

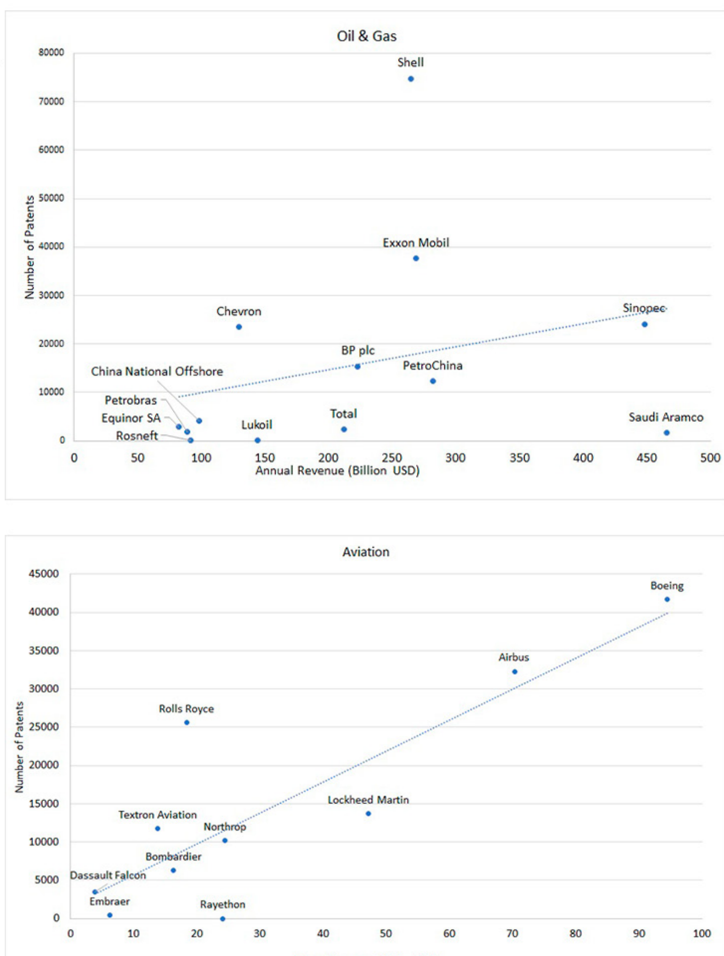

Figure 7. Number of patents (WIPO) by revenue for a) oil & gas and b) aviation companies.

However, the understanding of what these laws do or do not allow is conditioned by the guidance of public spending control bodies and public administration rules in general (Federal Accounts Tribunal – Tribunal de Contas da União – TCU; Solicitor General of Brazil - Advogacia Geral da União – AGU; Judicial Power in Brazil - Poder Juridico da União – PJU), and

Table IX. Impact of publications with Petrobras (SciVal).

	Petrobras	All University Collaboration	With UFRJ	Best in Brazil
Chemical engineering	0.83	0.85	0.91	2.42
Energy	1.09	1.13	0.98	2.01
Earth Sciences	0.97	1.01	0.80	1.24
Engineering	0.70	0.72	0.75	1.69
Environmental Science	1.00	1.07	0.77	2.36
Material Science	0.65	0.70	0.58	1.45
Mathematics	0.77	0.81	0.74	1.08
Social Science	0.48	0.53	0.33	1.19

entities representing the judiciary responsible for the defence of interests, such as the Public Defender's Office (Ministério Público) that may be affected by public managers' acts (McManus et al. 2020). These entities have a bureaucratic attitude and minor sensitivity to research management's peculiarities in universities and other academic institutions (Almeida 2014), especially in international collaborations. They are also more focused on control rather than outcome (Silva & Guimarães 2015), with a focus on "what is permitted is only what the law says" (Meirelles 2005).

Institutional inefficiency with University-Industry partnerships operates in the scientific scenario of inexperienced governance concerning technology transfer (TT) (Alves et al. 2015, Silva & Guimarães 2015), in addition to substantial bureaucratic barriers in universities, public institutions, and research institutes (Freitas et al. 2013) that result in informal partnerships (Dewes et al. 2015). Thus, researchers tend not to fully disclose their knowledge transfer activities to managers and/or administrators (Landry et al. 2010). According to Schwartzman (2002), the public sector is the leading partner and potential user of the knowledge generated by research in developing countries.

Wagner et al. (2015) hypothesise that how research is financed and measured may distract top thinkers from focusing on local needs. The shift towards global collaboration may present competition for rapid local assimilation of research results. These same authors show that the international system is highly influential in national, regional, and local scientific investment. This is discussed by Sampaio & Bonacelli (2018) in the case of biodiesel production in Brazil, where the formation of agricultural research networks favoured the construction of knowledge, research infrastructures and training of people but did not innovate biodiesel production. According to Gay (2014), Petrobras' low patent intensity is influenced by cultural, institutional and firm-specific factors. This author highlights how personal networks, bureaucracy, paperwork, and authoritarian leadership, leading to a lack of trust, affect the firm's results.

There is also a lack of strategic planning, both at the institutional level and in public policies, with clear goals in the short, medium and long term (Szapiro et al. 2016). Foreign companies show a higher impact with their top 10 partner institutions in Brazil (about 30%) than the Impact Factor of all their partners (McManus & Baeta Neves 2021), different from that seen here.

Studies show that patenting rates are low (Arundel & Kabla 1998) and depend on firm size. They are higher among firms that find

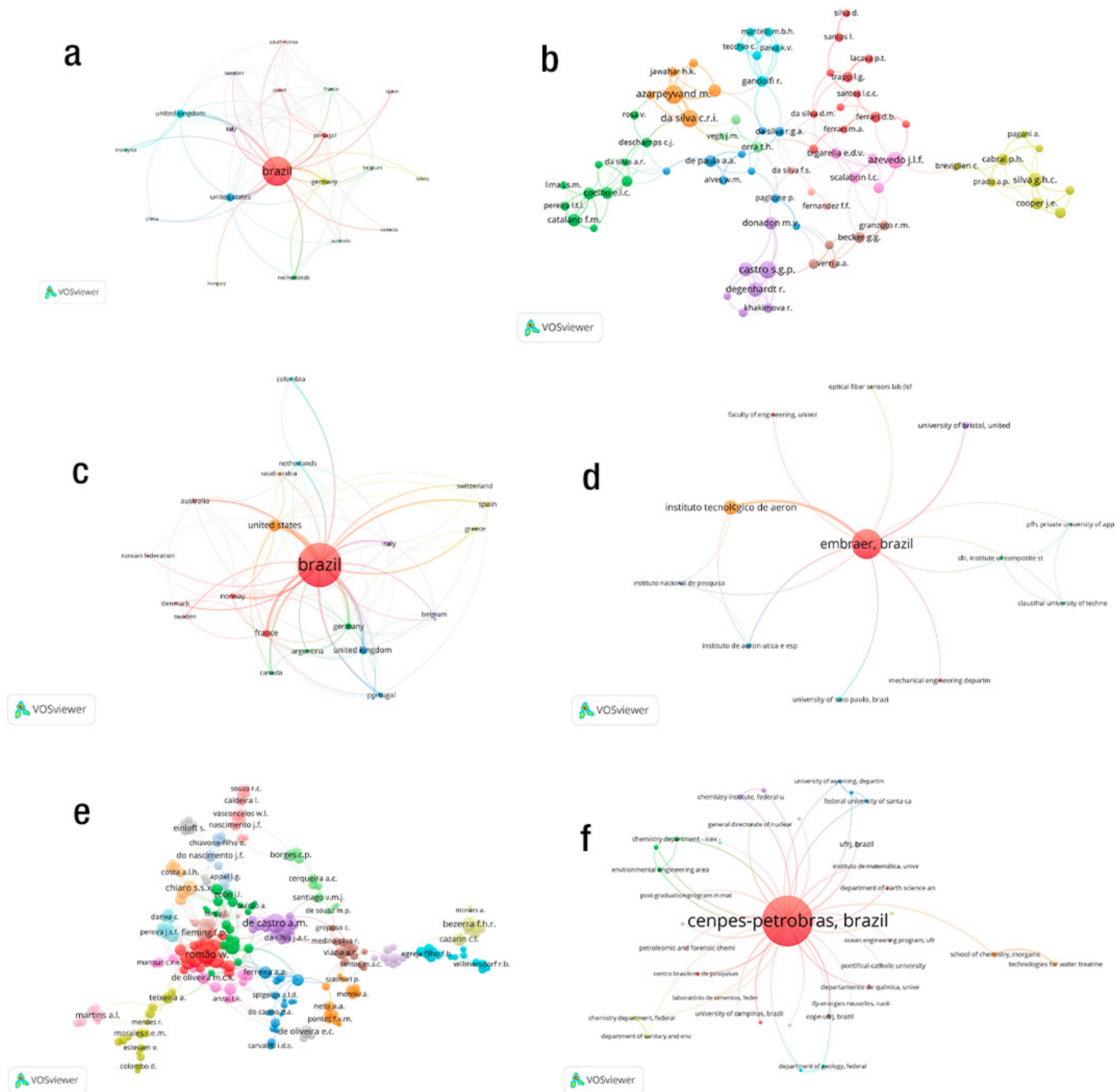

Figure 8. Co-author bibliographic mapping networks for Brazilian companies a), b) and c) for Embraer and d), e) and f) for Petrobras, by collaborating country, researchers and institutions respectively.

patents an important method for preventing competitors from copying product and process innovations. This same study showed that firms that find secrecy an essential protection method for product innovations are less likely to patent. Still, secrecy has little effect on the propensity to patent process innovations. Regarding Petrobras, organisational and geographical diversity has positively affected focal organisations' innovation performance through improving technological diversification (Zhang & Tang 2018). Petrobras' research budget is divided into internal calls or discretionary distribution of funds without open competition. Embraer (private) shows better results (Maculan 2013). This may be due to strategic network partnerships (Fonseca et al. 2017), improved governance (Silva et al. 2019), open access policy (Pinto & Costa 2019), science dissemination (Mansur et al. 2021) and international collaboration (Roa & Silva 2015).

The sector of activity has a strong influence on product patent propensities but minimal effect on process patent propensities after controlling for the impact of other factors. Huang & Cheng (2015) look at determinants of firms' patenting behaviours and found that larger firms and firms that exhibit a strong commitment to RD&I collaborations with universities have a lower propensity for non-patenting behaviours. Emodi et al. (2015) showed that Brazilian patenting was very low compared to the investment. Patenting may be misleading for assessing the innovativeness of the oil sector (Gay 2014), as State Owned Enterprises (SOE) are often adopters/emulators or incremental adjusters of critical technologies as opposed to original innovators. Most of their use of Innovation is often either incremental and/or not patentable. Enforcement capabilities are also necessary (Papageorgiadis & Sharma 2016).

Other types of measures of scholarly impact also exist which are not reflected in traditional citations as well as other forms of scientific communication among scholars, which are not necessarily connected to knowledge production directly (Chi et al. 2019), such as *usage, captures, mentions and social media* and show different aspects of research impact.

Glänzel et al. (1999) found that international cooperation is particularly advantageous for less advanced countries; network participation should enhance that advantage because it enables efficient collective search. The overall system (global and national) may become more productive and efficient but at the expense of national visibility and local connectivity. The need for science in networks and collaboration is also becoming more evident (OECD 2015). While the WIPO (2021) reports the quality of science and technology as fundamental to the quality of Innovation in the country, results here show that collaboration should be built on the best results and not those institutions that are physically close or where researchers have been formed or have close work ties.

Important international universities, such as Sweden, have adopted bolder policies in Innovation (Prokop 2021). They are moving towards other models of value appropriation beyond the dynamics of patenting and licensing of knowledge generated by scientific and technological research, involving the generation of academic spinoffs (Meoli et al. 2013). These startups, of the spinoff type, represent another innovation measurement mechanism in the dynamics of University – Company – Government interaction. It is vital to move forward in evaluating this process, seeking reliable data regarding the generation of startups in the academic context as an essential and modern mechanism for generating value derived from the dynamics of transforming knowledge into wealth, which characterises Innovation. Brazil shows some successful examples (Dal-Soto et al. 2021). These new mechanisms related to spinoff startups developed in the research context must be incorporated into the analysis of Innovation in a complementary way, yet no less important than the traditional analysis of patents and licensing.

CONCLUSIONS

Brazilian investment in science requires competition to flourish. Maintaining long-term research contracts without sunset clauses and effectively evaluating the resources employed is no longer possible. Brazilian science is used as a citation basis for patenting companies and universities worldwide but tends not to use this as a patenting source. USP is the major cited university, and Unicamp has more patents (both in the State of São Paulo). Brazilian universities, coupled with their foreign counterparts in academic-corporate collaboration, especially in the USA and Europe, can help increase the impact of scientific studies.

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SUPPLEMENTARY MATERIAL

Tables SI-SV.
Figures S1-S3.

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