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Article

Public policies and technological innovation in Brazil's oil and gas industry: a patent perspective

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ABSTRACT

The Oil & Gas (O&G) sector is the mainstay of Brazil's energy matrix. Given the complexity of the segment's activities, searching for new technologies and optimizing the effort and costs involved in the process are frequent objects of study for the players operating in this field. Based on this premise, there is a need to invest in innovative studies and research. The National Innovation System (SNI) is mainly responsible for promoting investment in Research, Development, and Innovation (RD&I) in the country, and patents are a relevant input in the technological production process. In this way, this research aims to investigate whether innovation promotion mechanisms influence the technological production of the main players in the Brazilian O&G sector. The methodology used consisted of the following steps: selection of the main regulatory frameworks related to NIS in the O&G sector; identification of the main Oil Companies, National Suppliers, and Research Units and their respective participation in ANP RD&I Clause projects, using the ANP's open database; a patent survey of the main players using the EPO's Espacenet open database; treatment and correlation of patent data in the light of the selected regulatory frameworks. The results showed that most of the players analyzed have the practice of technological protection through patents in the global context. However, only some companies linked to projects with resources from public policies to encourage innovation showed results that refer to Brazilian participation in the development of these patents. It becomes clear that certain regulatory frameworks have a major influence on patent production in Brazil, both positively and negatively.

1. Introduction

The oil and gas (O&G) sector plays a key role in Brazil's energy matrix and makes a significant contribution to the country's Gross Domestic Product (GDP). According to data compiled and presented by the Brazilian Oil and Gas Institute (IBP), in 2021, the O&G sector accounted for 47% of the national energy supply. In 2019, it contributed 15% of GDP in the industrial sector [1]. Considering the importance that the O&G sector represents globally and specifically at the national level in the economy, the interference of Research, Development, and Innovation (RD&I) productions is significant and needs to be treated seriously. The dilemma marked, on the one hand, by the strength of the Brazilian O&G sector and, on the other, by significant competitive gaps in Brazilian companies, caught the attention of the Brazilian government, which implemented public policies to encourage innovation and the production of local content to protect national interests. Regulatory frameworks came into effect for sectors in which private operators carry out some public utility activity with the intention of preserving the quality and reliability of the service provided, and just like in other sectors, they widely targeted the O&G sector. One of the main objectives of this intervention was to stimulate national competitive development through greater integration of local players capable of providing services and technologies [2, 3]. The 2004 Innovation Law [4] marked Brazil's first major boost to innovation, offering incentives for scientific and technological research. In 2016, Law No. 13.243, known as the Regulatory Framework for Science, Technology, and Innovation, significantly amended the 2004 Innovation Law and eight other federal laws. It established guidelines for scientific development, research, scientific and technological

training, and innovation, creating an initial framework for the National Science, Technology, and Innovation System (SNCTI). Federal Decree No. 9.283 of 2018 regulated the 2016 Law, providing details and clarifications to guide the application and implementation of the provisions, with an emphasis on cooperation between public and private entities [4, 5]. The Sectoral Funds began in 1999 with the Petroleum and Natural Gas Sectoral Fund (CT-PETRO) and aimed to finance national research, development, and innovation (RD&I) projects. CT-PETRO, funded by royalties from the O&G industry, aimed to boost scientific research in the oil, gas, and biofuels sectors, benefiting non-profit research institutions. The fund's rules prioritized partnerships between institutions and companies to develop projects. However, as of Law 10.197 of 2001, CT-PETRO began to lose some of its resources by contributing to the Human Resources Training Program of the National Agency for Petroleum, Natural Gas and Biofuels (PRH-ANP) and other cross-sector initiatives [3, 6]. The ANP introduced the Research & Development (R&D) Clause in oil concession contracts through Resolution 33 of 2005 and Technical Regulation 5 of 2005. This clause established that companies should allocate a percentage of their gross revenue to R&D activities. In 2015, ANP Resolution No. 50 and ANP Technical Regulation No. 3 replaced the 2005 rules, introducing Research, Development, and Innovation (RD&I) clauses in concession, production sharing, and onerous assignment contracts. ANP Resolution No. 799 of 2019 improved ANP Technical Regulation No. 3 of 2015, re-establishing the rules for the application of resources and proof of RD&I activities, adjusting destinations and percentages of distribution of resources according to bidding rounds [3,7]. Academia-industry-government relations called the "Triple Helix" [8], is the strategic basis of the structure known as the National Innovation System (SNI), responsible for developing and monitoring mechanisms to foster innovation between public and private entities. The NIS of the Brazilian O&G sector is divided into the following main groups: Oil Companies, which cover the stages of the extraction, refining, and distribution process; Suppliers, which produce the materials, equipment, and engineering services required in the various stages of the E&P process and product distribution; and Research Units, with support in basic or applied scientific or technological research or in the development of new products, services or processes [9].

One of the results of a good NIS is the production of patents. Miranda and Verde et al. [10] point out that patents are most often assumed to be a consequence of the production of knowledge, considering investments in RD&I to be an input in this process. However, they can also be understood as a production input to explain a company's productivity performance. The authors also point out that not all inventions are converted into patents, as there are scenarios where using the industrial secret system is more advantageous. Paula and Cavalheiro [11] address in their research a possible relationship between the number of patent applications following the discovery of the Pre-salt and the financial positions of players in the upstream O&G sector in Brazil. As presented in the work by Cavalheiro et al. [12], the results here indicate a growing interest in patenting technology related to pre-salt discovery in the country while noting that there must be other stimuli for this phenomenon. Deorsola et al. [13] concluded in their research on technological mapping through patents that the data obtained showed that Brazil has been making efforts in RD&I during the period used. Even with some crises in the O&G industrial sector, it has continued to develop, which may have influenced the constant public policies aimed at stimulating the national energy sector, which is strategic for the country's progress. There is an expectation that companies operating in the O&G sector in the country and making use of the public policies arising from regulatory frameworks such as the Sectorial Funds and the ANP's RD&I Clause are applying this money to the production of national technology. Although filing a patent or utility model application is not an obligatory stage in the RD&I process, one expects that the knowledge generated is safe in some way, and filing patent applications for utility models is the common way of guaranteeing the exclusivity of the invention produced in this process. Based on the premise that companies operating in the oil and gas market, whose technology acts as a competitive differentiator, are using the incentives of public policies to develop and protect local technology, which depicts patent applications, we finally arrive at the research question: Do innovation promotion mechanisms influence the technological production of the main players in the Brazilian O&G sector? Based on this question, this work has the following objectives: 1) To assess whether participation in ANP RD&I Clause projects is reflected in patent applications by the main Oil Companies, National Suppliers and Research Units that use these resources; 2) To assess whether the patent survey of these selected companies and institutions correlates with the main regulatory frameworks of the Brazilian O&G sector's NIS.

2. Methodology

Aiming to ascertain the impact of national regulatory frameworks in relation to patent filings to evaluate the technological production of the main players in Brazil's O&G sector, this research is classified as applied. The main type of procedure is documentary research, which involves analyzing documents carried out in a specific time frame and segment. The research used a time frame from 1995 to 2020 within the context of RD&I in Brazil's O&G sector. The definition of the time frame was motivated by the fall of Petrobras' monopoly and the minimum time for filing patents up to the date of this research. Based on the objectives presented for this research, the main variable used was the number of patent filings, with searches carried out on Espacenet in EPO [14], an open database for patent searches developed by the European Patent Office, using search terms in accordance with the database standard. The second research variable refers to ANP RD&I Clause projects, which classifies as the type of ANP Technical Regulation, Oil Company (operators), National Supplier (goods and services companies in the O&G sector with national legal entity registration), or Research Unit (institutions accredited by the ANP to carry out RD&I projects), with information collected through the open databases at ANP [15]. The third research encompasses the regulatory frameworks related to the NIS in the O&G sector, with the selection criteria coming from research carried out by the authors to compare and capture the existence of a correlation with the other variables presented.

The technique used in the study was descriptive statistical analysis. This type of data evaluation derives from the results obtained in the research, which are represented here by means of graphs that relate the various variables pre-established through historical bias, and the data found is compared with other existing data. Once the author notices the phenomena in the historical series studied, these will be discussed and interpreted considering the scientific literature produced up to this research's current moment of study. Finally, we address the results obtained by other authors and

their possible relationships with the sentences established after the data analysis of this research.

3. Presentation and analysis: Objective 1

3.1 The ANP's RD&I Clause as a mechanism for promoting technological production in Brazil's O&G sector

Regardless of the variations that occurred in the total volume of production and, consequently, in the total amount of mandatory investment, it was recorded in Figure 1 that there has been a steady rise in the percentage share of all other Oil Companies from 2% in 2010 to 27% in 2020. This behavior can be linked to the milestones of the legal and fiscal regime of the Pre-Salt, referring to the Laws enacted in 2010 (Law No. 12.351/2010, No. 12.304/2010, and No. 12.276/2010), through the intensification of external interest in the discoveries of significant hydrocarbon reservoirs and the bidding rounds for exploration and production of new fields [16].

Although it is not possible to establish a linear relationship between the number of RD&I projects and the number of mandatory investments in the ANP RD&I Clause in the year, as the number of resources for each project may vary depending on the company's strategic objectives and the sector's specific innovation development needs, the downward trend that began in 2005 in the number of ANP RD&I projects stands out. Figure 2 shows the year in which ANP Technical Regulation 5/2005 was implemented. The introduction of the ANP RD&I Clause in 2005 did not coincide with any change in the upward trend in the value of Petrobras' mandatory investments in the period in question. However, it is assumed that the 2005 milestone led to a decrease in the number of projects due to changes in the role of the ANP, which became responsible for analyzing, approving, monitoring, and supervising the use of resources from the ANP RD&I Clause [6].

Figure 2 shows that the first participation of National Suppliers in projects, according to ANP RT 5/2005, occurred only in 2009, with a maximum percentage of 3% of the total projects registered in 2013, 2014, and 2015. Lima-de-Oliveira [17] highlights a fact that corroborates this early increase in the participation of National Suppliers. The author points out in his work that only since 2013, during the 11th bidding round for blocks, have RD&I resources been able to be used in development programs for suppliers of goods and services based in Brazil. However, the average participation of National Suppliers increased in the projects according to ANP RT 3/2015, a factor which, according to Ferreira and Ramos [18], can be linked to the facilitation of the process for companies in the Technical Regulation of 2015 with the redefinition of guidelines and norms for the application of resources and rules for proving expenditure activities. Based on Figure 2, there has been 47% participation by Research Units since the first project in the time frame, registered in 1995 in the ANP TR 3/2015 database [3]. The institutions' partnership with Petrobras predates the regulatory frameworks selected for this study. In the projects, according to ANP RT 3/2015, the maximum participation peaks at 84% in 2009, with a subsequent drop to 10% in 2016 and a resumption of growth after the implementation of ANP RT 3/2015, with a maximum of 75% in 2018.

3.2 Selection and patent survey of the main players linked to the ANP's RD&I Clause

Table 1 shows the 04 Oil Companies selected for Group A, responsible for the mandatory investments and contracting of ANP RD&I Clause projects. The selection criteria used were Petrobras (A01) - the main national operator with a significant share of investments - and the Pareto method based on the investment values of the other Oil Companies (e.g., Shell, Petrogal, Repsol Sinopec) available in the ANP open database [15].

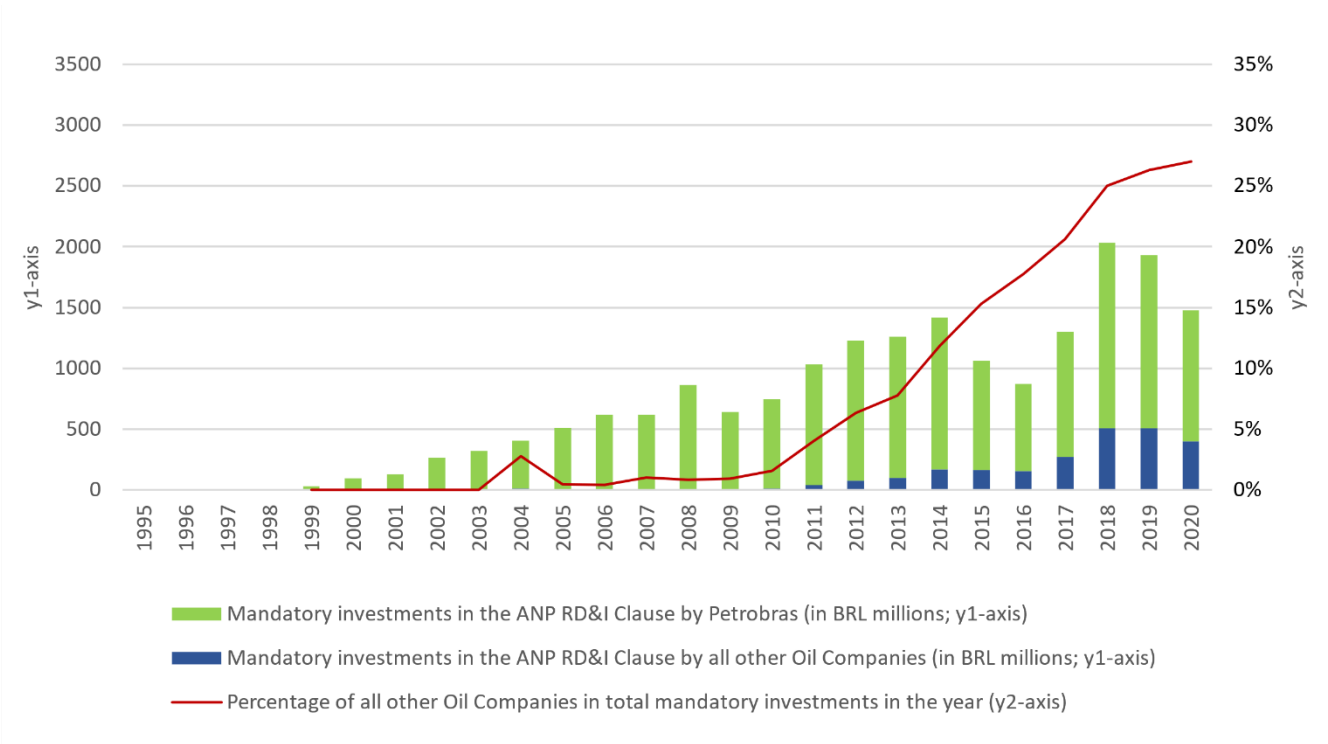

Figure 1. Mandatory investments in the ANP RD&I Clause by Petrobras and all other oil companies [15]

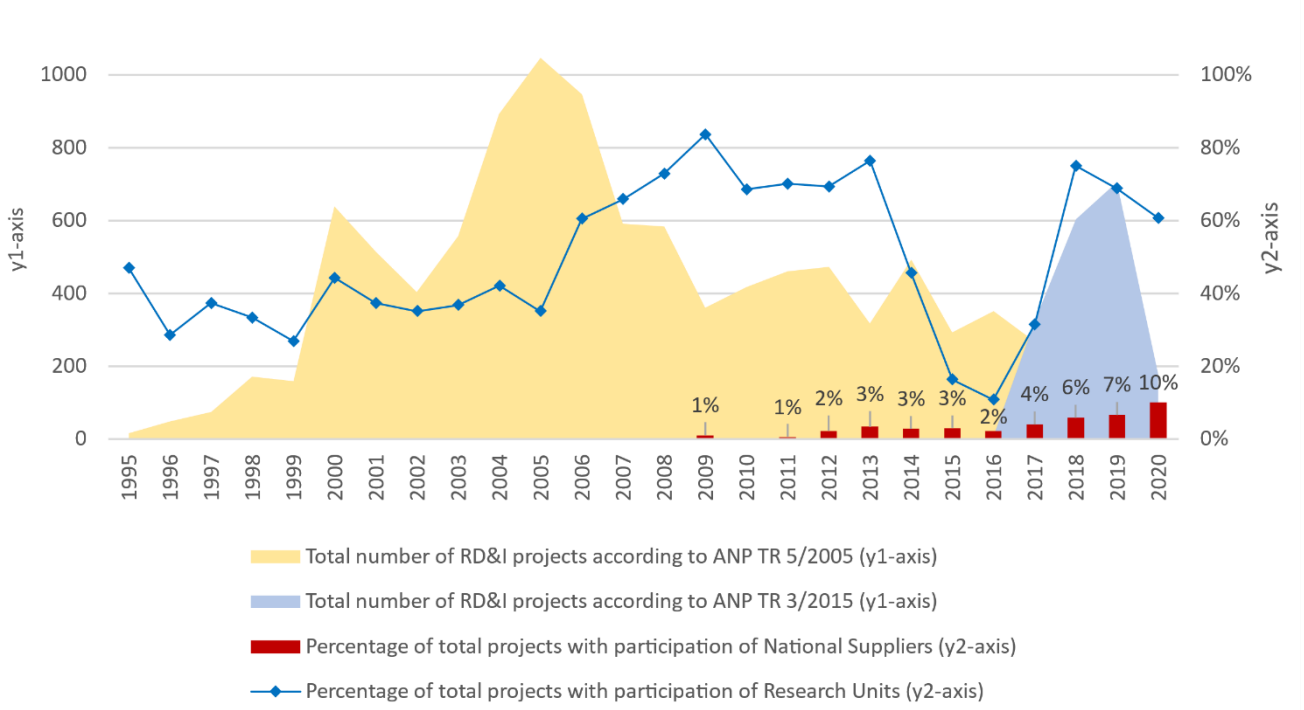

Figure 2. National Suppliers and Research Units participation in the ANP RD&I projects [15]

Table 1. Results of the group A patent search - oil companies

ID	Total number of patents in the world	Total number of patents protected in Brazil	Total number of patents with priority requested in Brazil	Patents with Brazilian co-participation	
				Total number of patents with Brazilian inventor	Total number of patents with Brazilian co-ownership
A01	1500	1408	1381	1474	1500
A02	8464	1796	5	7	1
A03	12	6	2	6	5
A04	281	29	2	13	1
Total	**10257**	**3239**	**1390**	**1500**	**1507**

Table 2 and Table 3 present, respectively, the patent survey of the 28 National Suppliers (e.g., Halliburton Serviços Ltda., Schlumberger Serviços de Petróleo Ltda., Alis Soluções em Engenharia Ltda., TechnipFMC Ltda.) and the 12 Research Units (e.g., Universidade Federal do Rio de Janeiro - UFRJ, Serviço Nacional de Aprendizagem Industrial - SENAI, Universidade de São Paulo - USP) selected for Group B and C, with ANP accreditation to carry out RD&I Clause projects. The Pareto method was used as a selection criterion, individually for each group, in terms of the number of resources accessed in ANP RD&I Clause projects and their respective shares. It is worth noting that the information considered for calculation refers to projects whose resource values were available in the ANP's open database [15]. The sample used for selection consisted mainly of projects between 2016 and 2022, according to ANP RT 3/2015. The criteria for identifying the patents with co-participation from O&G Companies of the Research Units, shown in Table 3, was to verify the co-ownership of at least one of the Oil Companies or National Suppliers registered in the ANP database [15] of RD&I projects.

3.3 Influence of RD&I Clause resources on the technological production of oil companies

The information shown in Table 1 shows that there is a high degree of disproportionality in the technological production strategies adopted by the Oil Companies. Of the total of 10,257 patents in the world mapped in the group, approximately 83% of the patents came from company A02 alone, followed by 15% from A01, while A04 and A03 accounted for just 2.7 and 0.1%, respectively. As one might expect, in Table 1, the proportion of patents protected in Brazil, patents with priority requested in Brazil, patents with Brazilian inventors, and patents with Brazilian co-ownership of A01 (Petrobras) exceeds in both cases, 92% of the Brazilian oil company's global patent portfolio.

Table 2. Results of the Group B patent search - National Suppliers [14]

ID	Total number of patents in the world	Total number of patents protected in Brazil	Total number of patents with priority requested in Brazil	Patents with Brazilian co-participation	
				Total number of patents with Brazilian inventor	Total number of patents with Brazilian co-ownership
B01	12047	2669	26	72	101
B02	12530	548	19	109	12
B03	2	2	2	2	2
B04	0	0	0	0	0
B05	1	1	1	1	1
B06	297	39	1	5	0
B07	92	0	0	0	0
B08	650	222	59	67	57
B09	1319	345	1	4	2
B10	8	8	8	8	8
B11	463	180	1	0	0
B12	0	0	0	0	0
B13	371	103	3	0	0
B14	0	0	0	0	0
B15	9954	2273	24	57	6
B16	97	0	0	0	0
B17	14	3	0	0	0
B18	0	0	0	0	0
B19	6249	325	10	6	9
B20	5	0	0	0	0
B21	0	0	0	0	0
B22	0	0	0	0	0
B23	3416	73	4	24	2
B24	1	1	1	1	1
B25	0	0	0	0	0
B26	337	182	3	0	0
B27	6	3	1	1	1
B28	1	1	1	1	1
Total	**47860**	**6978**	**165**	**357**	**203**

Table 3. Results of the Group C patent search - Research Units [14]

ID	Total number of patents in the world from any segment	Total number of patents with co-participation from O&G Companies
C01	597	65
C02	645	10
C03	349	26
C04	1451	14
C05	1398	15
C06	0	0
C07	108	1
C08	534	18
C09	181	7
C10	324	5
C11	297	9
C12	317	16
Total	**6201**	**186**

These proportions were low for other selected Oil Companies, with even lower results for A02 and A04's patents with priority requested in Brazil, patents with Brazilian inventors, and patents with Brazilian co-ownership. When analyzing Figure 3, Petrobras' production of patents in the world and patents protected in Brazil has followed the number of ANP RD&I projects contracted by the oil company over the years. However, Figure 4 shows that the behavior of patents protected in Brazil by other selected Oil Companies is incompatible with the number of RD&I projects contracted by them, according to the period of growth of RD&I projects contracted according to ANP RT 3/2015 from 2016 and the rare registrations of patents with priority requested in Brazil over the years.

3.4 Influence of resources from the ANP's RD&I Clause on the technological production of National Companies

It can be seen in Table 2 through the patents in the world variable that there is a significant difference between the patent production of the National Suppliers that participate most in ANP RD&I projects. Of the total of 28 companies selected, 25% of them did not submit any patents in the search carried out in this study. On the other hand, only 2 of the largest patent producers (B02 and B01) accounted for more than half of the total patents in the world for Group B. Table 2 also shows that the ratio of patents protected in Brazil to the total number of patents in the world was also a behavior that differed between the National Suppliers because although companies B08, B11, and B26, with significant numbers of patents, had ratios of more than 30% of patents protected in Brazil in relation to the total number of patents in the world, the same ratio for company B02, for example, responsible for the largest patent production in the group, was 4%. Still, about the proportion of patents protected in Brazil, the results compiled from Group B show that in Figure 5, there has been a steady decline since 2012, reaching almost zero in 2021, contrasting with a significant increase in total participation in projects according to ANP RT 3/2015 by companies since 2016.

It is also possible that the group's total number of patents with priority requested in Brazil over the years has remained the same as the increase in participation in projects mentioned above.

3.5 Influence of resources from the ANP's RD&I Clause on the technological production of Accredited Institutions

Except for C06, which did not file any patents, Table 3 shows a balanced distribution in the total number of patents in the world from any segment in the Research Units selected for Group C. However, when analyzing the patents with co-participation from O&G Companies, 5 of the 12 institutions had a proportion of less than 2% of the total number of patents. These include C01 and C03, whose patents related to the O&G sector represented 11 and 8%, respectively, of the total number of individual patents. It can be seen in Figure 6 two peaks with greater expression, one in 2006 and the other in 2019, in the compiled number of participations in ANP RD&I projects according to ANP RT 3/2015 and RT 5/2015, respectively, of the Research Units. It is important to highlight that the decrease in the number of participations in projects between 2014 and 2016 coincides with the reduction in the average number of patents with co-participation from O&G Companies in 2016 and 2017, which may relate to the transition period between the Technical Regulations.

4. Presentation and analysis: Objective 2

4.1 Regulatory milestones related to the innovation system in Brazil's O&G sector

As a result of a systematic review carried out by the authors, Table 4 shows the list of regulatory frameworks in the period between 1995 and 2020, which may have influenced, positively or negatively, the technological production of the main players in the O&G sector. Categorized according to the mechanism that promotes the Brazilian O&G sector's NIS (e.g. Sector Funds, ANP RD&I Clause, Innovation Law), the selected regulatory frameworks have also been numbered in the "Ref." column, chronologically, according to the year of implementation.

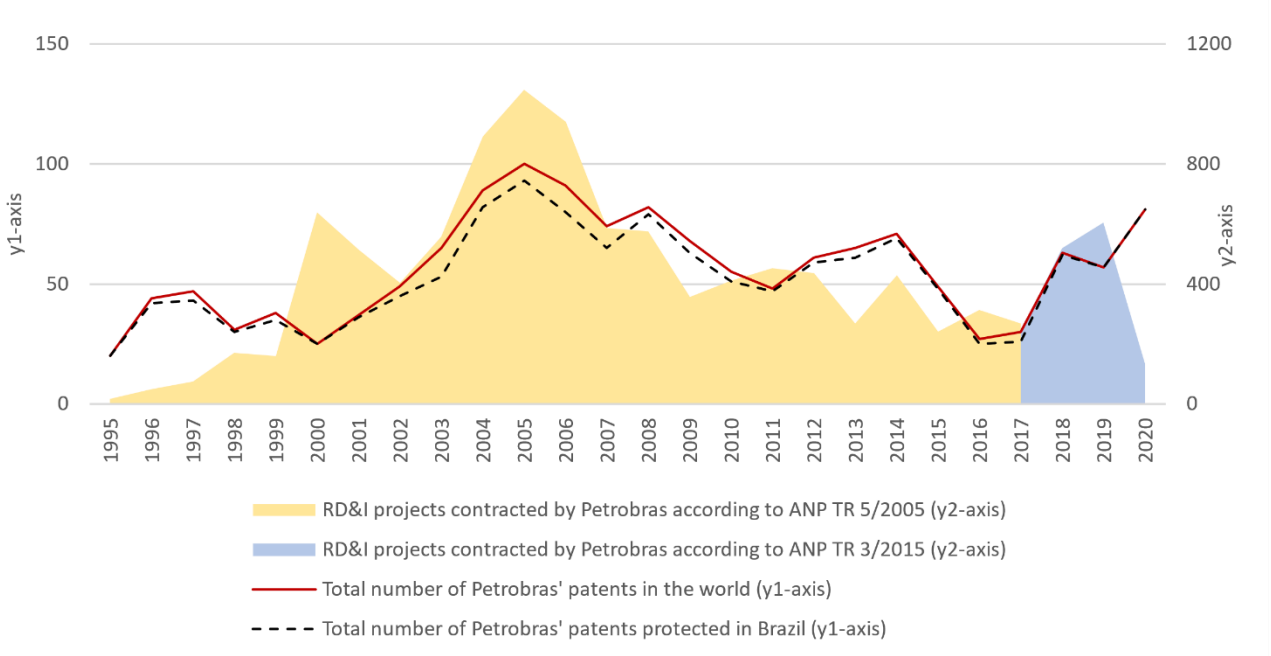

Figure 3. ANP RD&I projects contracted by Petrobras and its patent numbers [14, 15]

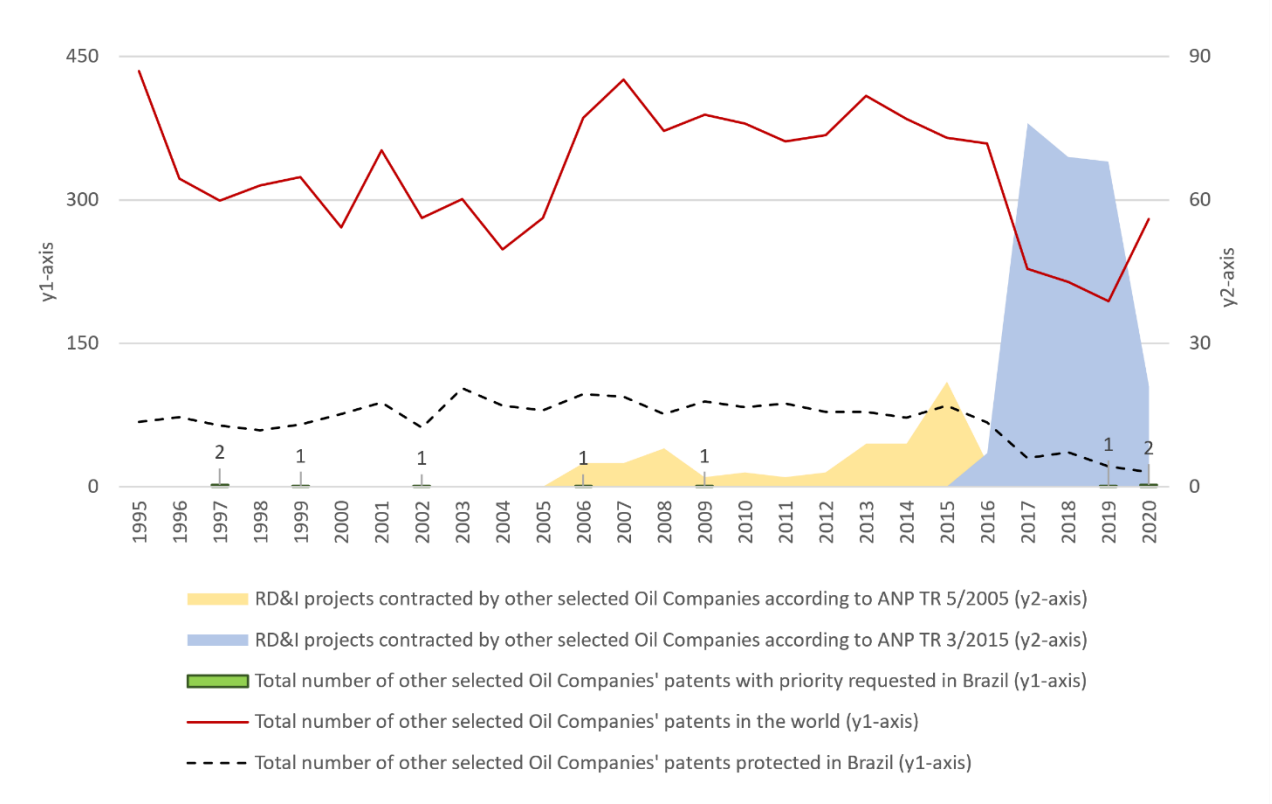

Figure 4. ANP RD&I projects contracted by other selected Oil Companies and their patent numbers [14, 15]

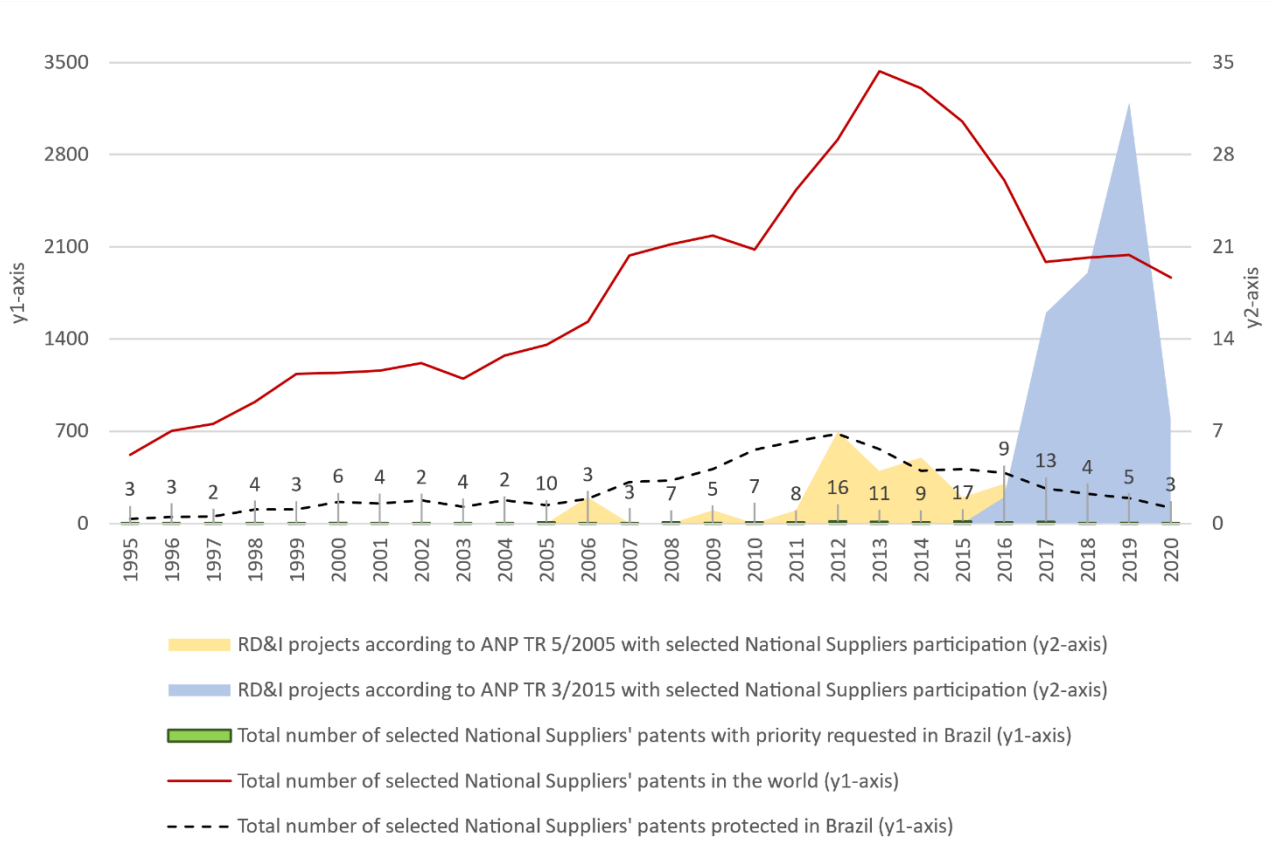

Figure 5. ANP RD&I projects with selected National Suppliers participation and their patents numbers [14, 15]

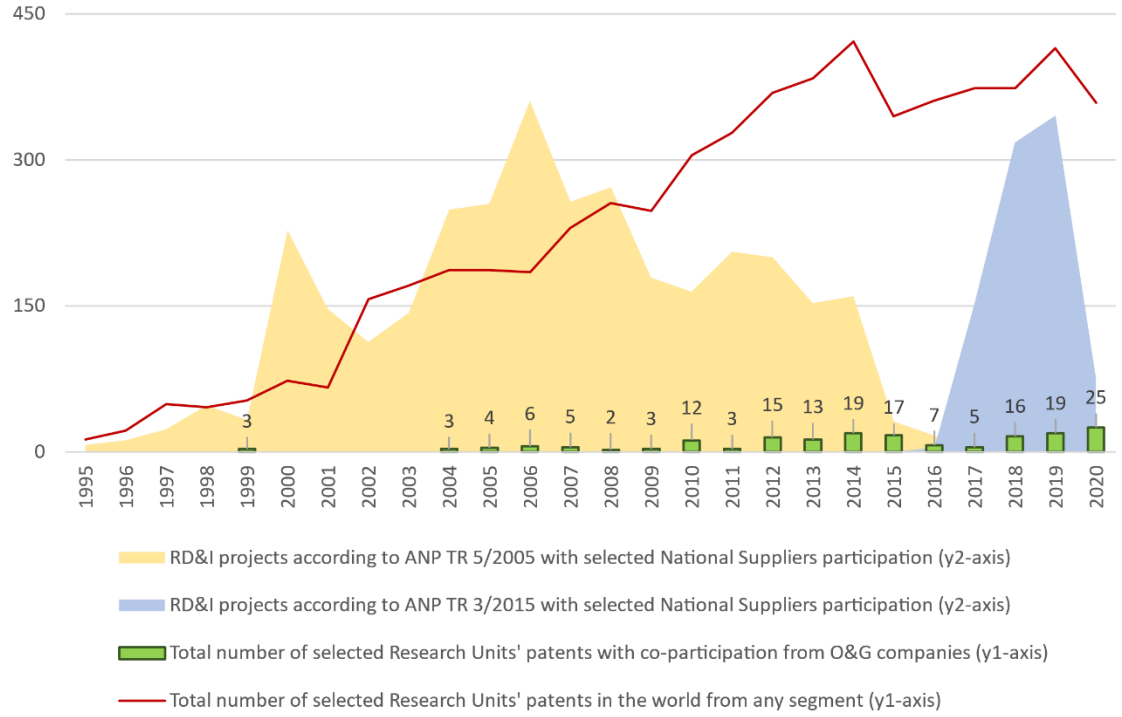

Figure 6. ANP RD&I projects with selected Research Units participation and their patent numbers [14, 15]

Table 4. Selected regulatory frameworks related to the NIS of the Brazilian O&G sector [3-7, 18]

Mechanism	Regulatory Framework	Year	Comments	Ref.
Sector Funds	Creation of the CT-PETRO	1999	Funding for RD&I projects from royalties generated by the O&G industry	RF1
	Redistribution of CT-PETRO resources	2001	Contributions to the PRH-ANP and other cross-sector initiatives	RF2
ANP RD&I Clause	ANP Resolution No. 33/2005 and ANP Technical Regulation No. 5/2005	2005	Introduction of the RD&I investment clause	RF4
	ANP Resolution No. 50/2015 and ANP Technical Regulation No. 3/2015	2015	Redefinition of guidelines and norms for the application of resources and rules for verifying activities and expenses	RF5
	ANP Resolution No. 799/2019	2019	Improving standards and changing the destinations and distribution percentages of resources	RF8
Innovation Law	Law No. 10.973/2004	2004	Creation of the Innovation Law; RD&I incentives for the country's industrial development	RF3
	Law no. 13.243/2016	2016	Regulatory Framework for Science, Technology and Innovation; re-established the main guidelines of the 2004 Innovation Law	RF6
	Decree No. 9.283/2018	2018	Details for applying the provisions of Law No. 13.243/2016 with a focus on cooperation between public and private entities	RF7

4.2 Influence of regulatory frameworks on the Brazilian technological production of the main players in the NIS in the O&G sector

The results presented in Figure 7 refer to the compiled number of patents with Brazilian co-participation (Group A and B) and patents with participation from O&G Companies (Group C) - the main players in the Brazilian O&G sector linked to ANP RD&I Clause projects -, the subsections below consist of observations in the light of the regulatory frameworks "Ref." listed in Table 4. In other words, the method of discussion and analysis presented here observes the chronological sequence of each mechanism without external correlations.

4.2.1 Regulatory milestones linked to the sectoral funds

RF1 refers to the creation of the CT-PETRO Sector Fund in 1999, with the aim of supporting the financing of national RD&I projects through royalties. Mendonça and De Oliveira [15] point out that by using non-profit research institutions as the target audience, the fund's rules establish preferences for approving projects for institutions that form partnerships with companies to develop projects.

As expected, when evaluating the national patent production of Petrobras, the main oil company in the national O&G sector, there has been a significant increase in the number of patents issued by the company worldwide since 1999, making it possible to correlate this behavior as a positive result of the RF1 and RF2 incentives. There was no impact on national patent production in the years immediately following RF1 and RF2 in the other selected Oil Companies. Observe that the redistribution of resources earmarked for CT-PETRO, highlighted by Mancini [6] due to contributions to the PRH-ANP and other cross-sector initiatives, which led to a drastic reduction in the amounts earmarked for RD&I, did not affect the technological production of the other Group A companies. As to producing patents by the National Companies in Group B, no significant changes emerged during the period of RF1 and RF2. These results can relate to the need for more involvement of national suppliers of goods and services in RD&I projects with the Research Units and the absence of partnerships with operators to develop technologies in the period.

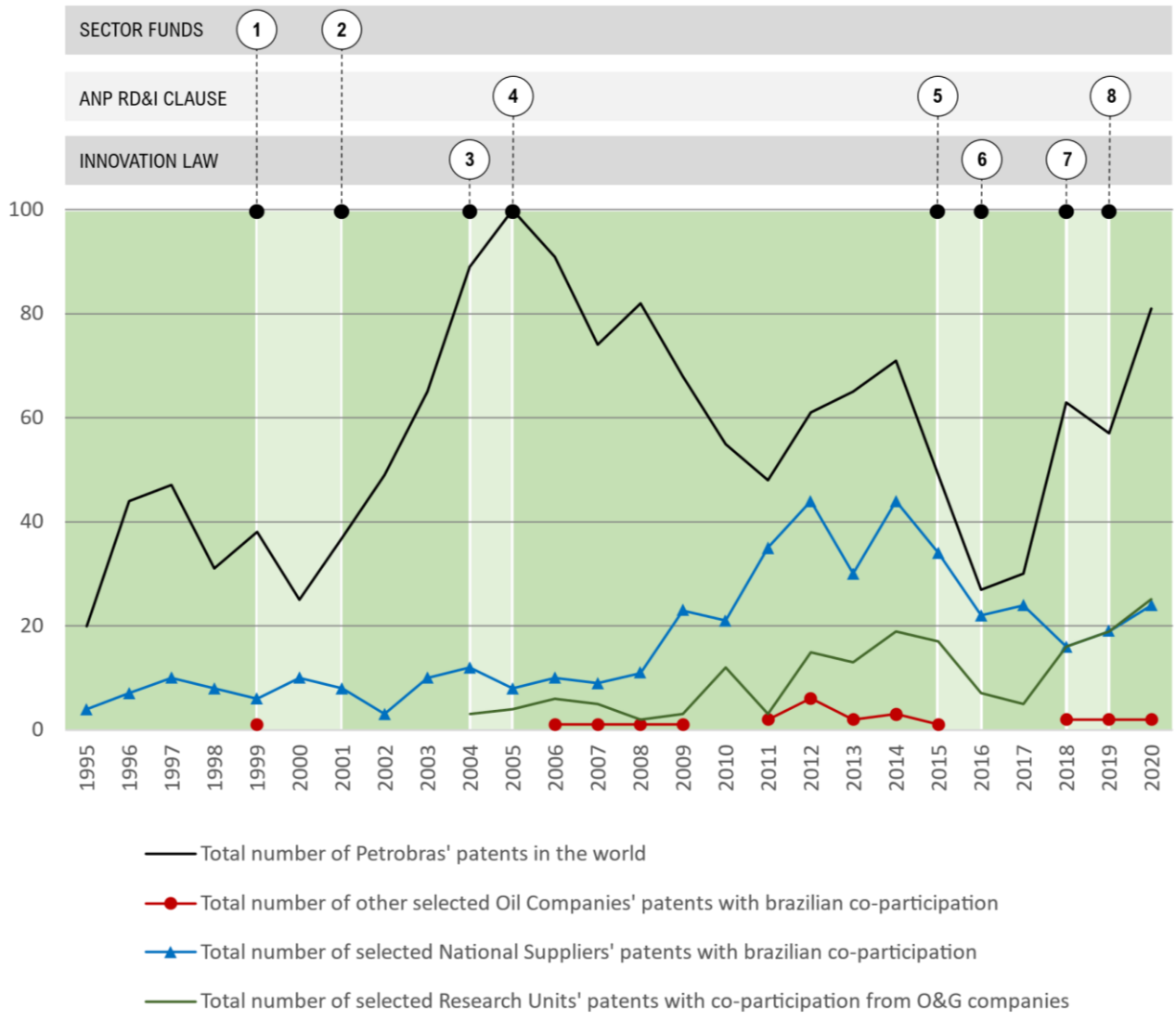

Figure 7. Correlation between selected regulatory frameworks and main players' patents with Brazilian participation in the O&G sector [14]

It corroborates the position of Da Silva [19], who points out in his study a strong dissociation between Petrobras' suppliers and RD&I projects involving CT-PETRO, justifying that the inhibitor of this process is the difficulty in defining a common agenda between suppliers and research centers due to the response time required for the activity. The results compiled from Group C of the Research Units did not show any patents with co-participation from O&G companies in the period of RF1 and RF2. Although the institutions selected in Group C do not cover all the Research Units involved in the O&G sector, such as the non-inclusion of CENPES (Centro de Pesquisas Leopoldo Américo Miguez de Mello - main Petrobras' Research Unit), for example, the negative result indicated corroborates the deficiency of the funding mechanism in promoting partnerships between the main players in the segment, resource providers, and the academic RD&I environment.

4.2.2 Regulatory milestones linked to the ANP's RD&I Clause

As highlighted by Mancini [6], RF4 refers to the introduction of the ANP RD&I Clause in 2005 through ANP Resolution 33/2005 and Technical Regulation 5/2005, which earmarked part of the gross revenue from the production of Oil Companies' fields as mandatory investment in expenses qualified as RD&I. Coinciding with the reduction in RD&I projects contracted by Petrobras shown above in Figure 3 the patent production results of Figure 7 show a high decrease in the main Brazilian Oil Company patent production after the implementation of RF4 in 2005, which contrasts with the continuous growth of mandatory investment amounts shown in Figure 1 for the same period. Based on the position of Mancini [6], it is customary to assume that the reason for these results at Petrobras may have been a reflection of changes in the role of the ANP, which became responsible for analyzing, approving, monitoring, and supervising the application of mandatory investments in RD&I. However, although not very significant, patent production with Brazilian co-participation of the other selected Oil Companies' reacted after RF4 of 2005, coinciding with the start of contracting RD&I projects of the other companies selected in Group A shown in Figure 4. As for the impacts of Group B's National Suppliers, we can see in Figure 7 an increase in the number of Brazilian patents in the period following the implementation of RF4. This growth coincides with the period of increased participation in RD&I projects according to ANP RT 5/2005 implemented by the regulatory framework.

Group C's Research Units also showed an increase in the number of patents co-owned by companies in the O&G sector after the implementation of RF4. Although the behavior of participation in RD&I projects in the period shown in Figure 6 was decreasing, the implementation of RF4 boosted the percentage of participation of Research Units in RD&I projects, as shown in Figure 2. Subsequently, RF5 of 2015, through ANP Resolution 50/2015 and Technical Regulation 3/2015, redefined the guidelines and norms for the application of resources and rules for proving the activity and expenses of ANP RD&I Clause projects [18]. Although RF5 for 2015 coincides with a decrease in the number of patents for all groups, according to the information in Figure 7, in all cases (results compiled from Groups A, B, and C), the transition year with the start of the period of decline was 2014, which precedes the implementation of RF5. Therefore, RF5 may have contributed to the reduction in Brazilian patent production, but it cannot be considered the root cause of this behavior.

The last regulatory framework related to the ANP RD&I Clause in the time frame of this research took place in 2019, RF8. According to ANP [1], the ANP Resolution 799/2019 aimed to improve RF5 by re-establishing the rules for the application of resources, changing the destinations and percentages of resources collected, and optimizing the rules for proving RD&I activities. Figure 7 shows that the year 2019 coincides with a period of growth in the production of Group A, B, and C patents.

4.2.3 Regulatory milestones linked to the innovation law

Not exclusive to the Brazilian O&G industry, RF3 refers to the creation of Law No. 10.973, known as the "Innovation Law", in 2004, which, as described in Federal Law no 10.973 of 2004 [4], provided incentives for RD&I, establishing measures to build capacity and achieve technological autonomy. Based on the results compiled from all the groups in Figure 7, no common behavior or variation in the number of patents in the year RF3 was found. It corroborates the position of Miranda and Verde [10] when they state that the 2004 Innovation Law included distorted incentive mechanisms and difficulties in the interaction between ICTs and companies, resulting in a lack of effectiveness in the collaboration between the public and private sectors in innovation in Brazil. The movements inherent in RF6 and RF7, through the implementation of Law No. 13,243 of 2016 and Federal Decree No. 9,283 of 2018, respectively, which became known as the "Regulatory Framework for Science, Technology and Innovation" (MCTI), reflected positively on the patent results of Groups A, B, and C shown in Figure 7. The period of implementation of the frameworks was one of growth. Although it is not possible to link the results due to the influence of the other mechanisms and frameworks of the period, it is assumed that the points highlighted by Miranda and Verde [10] in their legal analysis that the MCTI helped to reduce obstacles to private negotiation, reduce bureaucracy in administrative procedures and expand the possibilities for interaction between public and private agents, where the proportion of Industrial Property (IP) and participation in the results make up the negotiations, revealing an undeniable reduction in obstacles to private negotiation.

5. Conclusion

This study examined whether participation in ANP RD&I Clause projects influences the patenting activity of key players in Brazil's Oil & Gas sector. The findings indicate a significant disparity in patenting strategies among major Oil Companies, with Petrobras demonstrating a strong correlation between RD&I investments and patent production, whereas other selected Oil Companies showed limited national patent filings despite their participation in ANP-funded projects. National suppliers displayed inconsistent patenting behavior, with only a few actively seeking patent protection in Brazil. Research units, on the other hand, played a relevant role in fostering patent co-ownership with industry partners. Regarding the second objective, the study confirmed that specific regulatory frameworks directly impacted patent output, either positively or negatively. The implementation of the CT-PETRO Sector Fund in 1999 led to increased RD&I investments and patenting activity, particularly for Petrobras. Conversely, the introduction of ANP Technical Regulation 5/2005 resulted in a decline in Petrobras' RD&I projects despite rising

investments. Additionally, the Science, Technology, and Innovation Regulatory Framework of 2016–2018 contributed to reducing bureaucratic barriers and fostering stronger collaborations between industry and research institutions. These findings highlight the critical role of regulatory mechanisms in shaping innovation outcomes. While public policies aim to stimulate local technological development, the actual impact on patent production varies depending on company strategies, industry dynamics, and policy implementation. Future research could explore comparative analyses with other countries, assess alternative RD&I indicators beyond patent filings, and investigate the long-term effects of innovation policies on the sector's technological competitiveness.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

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