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Oil sector and technological development: Effects of the mandatory research and development (R&D) investment clause on oil companies in Brazil

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ABSTRACT

The commodity boom at the turn of the millennium spawned growing interest in development strategies based on natural resources. The Brazilian government introduced a groundbreaking contractual clause to force oil companies to invest into research and development (R&D) 1% of gross revenues from large oilfields, with the aim of fostering technological development. To analyze the impacts of the R&D clause, we conducted 73 in-depth interviews with key informants from the oil sector. We also carried out a survey of 156 project coordinators. Our findings suggest that the R&D clause has strengthened the contribution to technological development by the national oil company, meanwhile involving new actors. The R&D clause has also boosted scientific research, technological capabilities, and innovation. However, it had a minor impact on fostering the relations between oil companies and service companies, and technology-based firms have played only a minor role.

1. Introduction

The role of natural resources in economic development has been widely discussed (Hirschman, 1964; Auty, 1994; Sachs and Warner, 2001). In the wake of the commodities super-cycle of the early 2000s, the debate among policy makers and academics has gained momentum. A consensus has emerged among scholars over which policy areas intended to secure the exploitation of natural resources may be most conducive to development (Sigam and Garcia, 2012; Sinnott et al., 2010; Håvard et al., 2015).

In particular, two dimensions have been underlined: the fiscal and the productive. The former, which has been investigated most, focuses on macroeconomic management of rents generated by the exploitation of natural resources. This approach examines policies to prevent negative impacts such as rentism and Dutch disease, as well as to secure the proper use and distribution of rents.[1] The productive dimension, meanwhile, investigates policies aimed at fostering productive linkages across all sectors. This perspective has acquired major relevance in recent years, as most developing countries have attempted to emulate the development path of Asia's newly industrialized countries (NICs). For this reason, several countries have adopted industrialization strategies based on natural resources (Adewuyi and Oyejide, 2012; Teka, 2012; Paz, 2014).[2] Some works suggest that the impacts of those strategies may differ due to the presence or absence of a prior industrial base, or due to distinctive features of the institutional framework (Pegg, 2006; Lederman and Maloney, 2008; Mancini and Paz, 2016). However, scholars have paid little attention to technological development, which appears to be crucial in fostering productive linkages (Pérez, 2010). Here we broadly define technological development as the process of adaptation, diffusion, or innovation of technology deployed in any productive activity. As the international diffusion of technology has been historically uneven and asymmetric (Stewart, 1977; Fischer, 2015) from a development perspective, this process plays a major role.

Earlier research demonstrated that technological development was vital to foster industrialization in the Asian NICs (Amsden, 1989), as well as in other countries with abundant natural resources (Torres-Fuchslocher, 2010). Technological development is therefore of utmost relevance to developing countries with abundant natural resources wanting to embrace a non-rentist or non-extractivist model of exploitation. But what factors can contribute to assisting that process?

Sabato and Botana (1970) argued that, to foster innovation, coordinated action is needed between the national government, the productive system, and scientific organizations. They argued that the state should implement a national strategy to enhance and coordinate interrelations among the actors involved in technological development. However, this interaction is constrained by the specific historical and structural characteristics of developing countries (Katz, 1976). Because technological development is understood as an evolutionary process,

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[1] See Ross (1999).

[2] As our goal is to examine the technological dimension, we will not address the debate on social and environmental issues related to the exploitation of natural resources.

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path-dependence is critical. And as it appears to be a collective process, it requires the collaboration of a network of involved actors (Mazzucato, 2013). In sum, we shall examine the interplay between those actors – the state, firms, universities, and research centers − and institutions, including the structural characteristics of the country. Within this framework, we shall investigate technological development in the Brazilian upstream oil sector, to assess its impacts and its evolution.

The case of Brazil is engaging for three major reasons. First, the national government has adopted specific measures to foster technological development in the oil sector. After the breakdown of the state monopoly, the government introduced a groundbreaking contractual clause to force oil companies to invest 1% of gross revenues from large oilfields into research and development (R&D), with the aim of boosting technological development. We investigate whether the R&D clause represents a major instrument of a resource-based development strategy, or whether it is part of a strategy to attract investments to stimulate technological development in the oil sector.

Second, as we will see in Section 2, the R&D clause forces technological cooperation between oil companies and science and technology organizations (STOs). As per the definition of the National Agency for Petroleum, Gas, and Biofuels (ANP in Portuguese), STOs can be either public or private universities or research centers. In this regard, Brazil provides a salient opportunity to investigate the driving factors of technological development and to examine the interplay between institutions and public and private actors.

Third, within the current political context marked by revision of the regulatory framework in the Brazilian oil sector, an assessment of current regulation is meaningful. As a large share of Brazilian oil and gas production and reserves is located offshore, especially in the pre-salt area (ANP, 2017),[3] exploration and production (E&P) is exposed to major technological challenges related to the extreme physical and chemical conditions of oilfields. Therefore, it is crucial to examine whether the adopted policy has contributed to overcoming these challenges and to enhancing technological development. In short, what are the scope and limitations of this policy, and notably of the R&D clause as its major instrument?

Early research on the Brazilian oil sector addressed the evolution of knowledge networks around the national oil company, Petrobras, until the 2000s (Dantas and Bell, 2009, 2011). Silvestre and Dalcol (2009) investigated the relation between geographical proximity and innovation within a given agglomeration of suppliers to the oil sector. Other studies examined the effects of joint research projects undertaken by Petrobras and several Brazilian universities (De Oliveira and De Oliveira Figueiredo, 2013; Porto et al., 2013; Turchi and Porto, 2013; Turchi et al., 2013). Nevertheless, to the best of our knowledge, our paper represents the first attempt to investigate the impacts of the R&D clause, by examining how it affects technological development through its consequences on the strategies of the actors involved.

Our method consists of a structured case study, based on field research conducted between June 2015 and February 2016. Our approach is consistent with Yin (2003): qualitative research methods are the preferred strategy when the researcher seeks to answer questions of "how" and "why", and when the behavior of the studied population cannot be controlled. Primary data were collected through self-administered questionnaires, semi-structured interviews, and direct observation.[4] Secondary data were gathered mainly through the ANP database and reports by companies.

Our work is organized as follows. Section 2 outlines the features of the R&D clause and examines the investments it has generated. Section 3 investigates the impacts of the clause on the strategies adopted by the various actors involved, along with the technological advancements achieved. Finally, we discuss the main conclusions of our research.

2. The R&D clause: characteristics and investments generated

Within the context of privatization policies inspired by the Washington Consensus, in 1995 the Brazilian government urged the Congress to approve Constitutional Amendment No. 9, which allowed for foreign investments in the oil sector. Two years later, the Congress passed Law 9478/1997, known as the Petroleum Law, which ended Petrobras' monopoly and opened the sector to market competition. Although a substantial share of Petrobras' equity was sold off to the market, the national government kept a major equity share with voting rights.

The Petroleum Law established the ANP, which assumed the mandate to regulate the oil, gas, and biofuels sectors, as well as to promote competition through bidding rounds on oil and gas concessions.[5]

Among other functions, article No. 8 of the Petroleum Law awarded the ANP the responsibility to stimulate the research and adoption of new technologies for exploration, production, transport, refining and processing of oil and gas. On that basis, in the "zero" bidding round held in 1998,[6] the ANP imposed a contractual clause to force Petrobras to invest into R&D 1% of gross revenues from the production of large oilfields subject to the payment of the Special Participation in any given trimester.[7] In 2005, the ANP approved a set of new regulations by which any oil company that signs a contract to explore, develop, and produce oil and gas must comply with the 1% obligation. The R&D clause was regulated by ANP resolutions 33/2005, 34/2005, and 46/2013, and by ANP technical regulations 5/2005 and 6/2005.[8]

The clause establishes that at least 50% of the mandatory value − reduced to 40% for the contracts signed after the tenth bidding round − must be invested in R&D projects undertaken by any STO accredited by the ANP; again, an STO is defined as a non-profit public or private university or research institute located in Brazil. On the other hand, as much as the remaining 50% of the mandatory value may be invested by the concessionaire in its own facilities, or in those of its affiliates, or in collaboration with any oilfield services and equipment company (hereafter, service companies) established in Brazil.

The R&D clause applies not only to the oil companies with concession agreements but also to those subjected to other contractual regimes, as follows. Production-sharing agreements[9] require oil companies to invest at least 10% of the mandatory value in R&D projects in partnership with service companies. Contracts signed under the onerous transfer-of-rights regime[10] benefit from a reduced requirement: oil companies must invest 0.5% of gross revenues from oilfields subject to Special Participation, but they can only fund research projects undertaken by STOs, not by firms.

[3] In 2016, 94.0% of oil production and 94.9% of oil reserves were offshore. In the same year, 77.0% of gas production and 88.0% of gas reserves were offshore (ANP, 2017).

[4] See annex for details on respondents to questionnaires and interviews.

[5] The Petroleum Law implemented a bidding system to offer exploratory blocks to the market. The first bid occurred in 1999 and, so far, 14 rounds have been launched. In October 2017, two additional rounds were promoted.

[6] The "zero" bidding round was held in 1998 to ratify the rights of Petrobras on a few blocks it had controlled prior to the end of the state monopoly.

[7] Gross revenues are calculated based on ANP resolution 12/2012. Special Participation is a financial contribution due to the federal government in each trimester which applies to oilfields with very large production. It is regulated by article No. 50 of the Petroleum Law, and by Decree 2705/1998.

[8] In 2012, ANP resolution 34/2005 was revoked by ANP resolution 47/2012. In the same year, ANP technical regulation 6/2005 was revoked by ANP technical regulation 7/2012. In 2015, ANP resolutions 33/2005 and 46/2013 were revoked by ANP resolution 50/2015. In that same year, ANP technical regulation 5/2005 was revoked by ANP technical regulation 3/2015. In sum, the R&D clause is currently regulated by ANP resolutions 47/2012 and 50/2015, as well as by ANP technical regulations 7/2012 and 3/2015.

[9] The production-sharing regime is regulated by Law 12351/2010.

[10] Law 12276/2010 established an onerous transfer of rights from the Federal Union to Petrobras to explore certain specific offshore blocks assigned to the company without auction.

Table 1
Investments generated by the R&D clause (1998–2015), in millions of BRL.
Source: our elaboration based on data from database on R&D investments of ANP available online.

Year	Petrobras		Other oil companies[a]		Total investments (all companies)		Annual percent change (nominal)	Annual percent change (real)
	nominal	real[b]	nominal	real[b]	nominal	real[b]		
1998	1.88	1.88	N/A[c]	N/A[c]	1.88	1.88	…	…
1999	29.00	28.30	N/A[c]	N/A[c]	29.00	28.30	1442.6	1405.3
2000	94.20	84.93	N/A[c]	N/A[c]	94.20	84.93	224.8	200.1
2001	127.27	109.54	N/A[c]	N/A[c]	127.27	109.54	35.1	29.0
2002	263.54	209.77	N/A[c]	N/A[c]	263.54	209.77	107.1	91.5
2003	323.30	230.32	N/A[c]	N/A[c]	323.30	230.32	22.7	9.8
2004	392.59	260.42	11.12	7.38	403.70	267.79	24.9	16.3
2005	506.53	322.86	2.28	1.45	508.81	324.32	26.0	21.1
2006	613.84	379.07	2.55	1.57	616.39	380.64	21.1	17.4
2007	610.24	370.41	6.26	3.80	616.50	374.21	< 0.0	− 1.7
2008	853.73	502.48	7.13	4.20	860.86	506.68	39.6	35.4
2009	633.02	358.89	5.86	3.32	638.88	362.21	− 25.8	− 28.5
2010	735.34	407.40	11.58	6.42	746.92	413.81	16.9	14.2
2011	990.48	529.78	41.42	22.15	1031.90	551.93	38.2	33.4
2012	1148.76	595.08	77.92	40.36	1226.69	635.45	18.9	15.1
2013	1161.79	583.11	98.08	49.23	1259.87	632.34	2.7	− 0.5
2014	1246.47	608.62	161.10	78.66	1407.57	687.28	11.7	8.7
2015	894.00	423.64	136.96	64.90	1030.96	488.54	− 26.8	− 28.9
Total	*10,625.99*	*6006.50*	*562.24*	*283.45*	*11,188.23*	*6289.95*	…	…

Notes: .
[a] Other oil companies have been forced to comply with the R&D clause since 2005; however, a part of the mandatory investment has been accounted for the year 2004, because the obligation is based on the application of Special Participation in the prior period.
[b] Real terms are calculated with base year 1998 = 100, using the annual Consumer Price National Index (INPC) published by the Brazilian Institute of Geography and Statistics (IBGE).
[c] Not applicable.

It is noteworthy that the R&D clause was introduced as a separate instrument from other policy measures. In particular, in 2004, under the presidency of Lula da Silva, the national government promoted industrial policy through the Industrial, Technological and External Trade Policy, and through the introduction of local-content requirements in the oil sector. However, no mechanisms were introduced to link the activities funded by the R&D clause with those initiatives.

Mandatory investments generated by the R&D clause have gradually increased over time, totaling BRL 11.2 billion in 1998–2015, or BRL 6.3 billion in real terms.[11] As Petrobras has maintained a dominant position in the oil sector after the end of the monopoly, the national company has been the major contributor to the scheme (Table 1).

From 2006 − when the regulatory framework of the R&D clause entered into force for all companies − until 2015, the ANP authorized 1361 projects undertaken by STOs, corresponding to BRL 4.6 billion (Table 2).

It is worth investigating how the investments prompted by the R&D clause have benefited STOs vis-à-vis oil companies and service companies. Based on primary data, we estimate that STOs received a slightly higher share than the minimum established by the R&D clause, which is 50% of the mandatory value. On the other hand, oil companies, mainly Petrobras, invested the largest share of resources not mandated toward STOs to projects undertaken in-house. Indeed, Petrobras invested most of what it was not compelled to transfer to the STOs into its own research center. This is in sharp contrast with other oil companies, which invested only scant amounts internally. Finally, service companies received less than 10% of total investment to undertake research projects generated by the R&D clause.

One telling result of our research was that most of the international oil companies (IOCs) have invested into R&D precisely enough to comply with their obligation. Interviewees confirmed that oil companies have invested in R&D only because they were forced to do so by the clause. However, we should acknowledge that these companies entered into the upstream sector only few years prior to implementation of the R&D clause. However, four oil companies − BG, Chevron, Shell, and Statoil − have invested more than the obligation established by the mandatory R&D clause. Moreover, BG and Statoil have each established a research center in Rio de Janeiro. This was the first research center for BG outside its home country, while for Statoil, it was the first such center in a developing country.[12]

Because the IOCs have assigned a large share of their mandatory investments to STOs, as revealed by interviews, their contributions to technological development will be addressed through analysis of the STO research projects undertaken. Examination of Petrobras' contribution requires deeper investigation, due to its historical leadership in the sector; therefore, we shall address it first.

3. Actors, strategies, and technological results

The world oil sector has undergone considerable transformations in recent decades. Since the 1980s oil glut, oil companies have progressively outsourced their non-core business activities to service companies. These firms have specialized in high-tech activities and became the largest spenders in terms of R&D within the oil sector (Perrons, 2014; Rassenfoss, 2016). Two main strategies have driven investments in technological development by both oil companies and service companies: cost reduction, and the exploitation of new reserves, especially in deep water.

The interplay between oil companies and service companies is a major feature of the upstream oil sector. The former have adopted a model of "open innovation" that entails a collaborative approach by involving both service companies and STOs (Chesbrough, 2003; Henni,

[11] Real terms are calculated with base year 1998 = 100, using the annual Consumer Price National Index (INPC) published by the Brazilian Institute of Geography and Statistics (IBGE).

[12] Statoil inaugurated Research Center Rio in 2011. The company owns two other research center in its home country of Norway and in Canada. BG invested in a research center within the Technological Park at the Federal University of Rio de Janeiro; moreover, the company has launched the Research Center for Gas Innovation at the University of Sao Paulo.

Table 2
Total investments generated by the R&D clause.
Source: our elaboration based on data from the database on R&D investments of ANP available online.

Company	Mandatory investments (1998–2015; millions of BRL)	% of total	Investments in STOs (2006–2015; millions of BRL)	No. of projects funded in STOs	% of total
Petrobras	10,625.99	94.97	4312.32	1234	92.9
BG	172.88	1.55	193.77	39	4.2
Repsol-Sinopec	84.29	0.75	10.36	10	0.2
Statoil	83.21	0.74	36.86	19	0.8
Sinochem	55.47	0.50	16.96	12	0.4
Petrogal Brasil	49.95	0.45	20.57	12	0.4
Chevron	27.71	0.25	6.37	9	0.1
Shell	23.87	0.21	23.51	5	0.5
Queiroz Galvão E&P	23.60	0.21	7.43	5	0.2
Frade Japão	9.78	0.09	3.16	1	0.1
Parnaíba Gas Natural	6.55	0.06	8.31	2	0.2
Brasoil Manati	5.25	0.05	0.24	2	< 0.1
GeoPark Brasil[a]	5.25	0.05	0.78	4	< 0.1
ONGC Campos	4.95	0.04	0.50	2	< 0.1
QPI Brasil Petróleo	3.47	0.03	0.19	2	< 0.1
BPMB Parnaíba	2.81	0.03	0	0	0
BP[b]	1.93	0.02	2.32	2	< 0.1
Maersk Oil	1.29	0.01	0	0	0
Total Brasil	N/A[c]	N/A[c]	0.09	1	< 0.1
Total	*11,188.23*	*100*	*4643.76*	*1361*	*100*

Notes: .
[a] Includes the obligations of the company Rio das Contas, which was acquired by GeoPark Brazil in 2014.
[b] The ANP authorized BP to invest in two R&D projects for a higher value than its obligation.
[c] Not available.

2015). Considering this interrelation, we have investigated the strategies of the actors involved in the R&D clause and their contributions to technological development. First, we examine Petrobras, the leader in this regard: in 2016, the company accounted for 81.5% of national oil production and 78.6% of domestic natural gas production (ANP, 2017).[13] Afterward, we analyze service companies and STOs.

3.1. Petrobras

The Brazilian oil sector operated under state monopoly from 1953, when Petrobras was set up, to 1995, when the sector was opened to competition. Technological development prior to implementation of the R&D clause was marked by Petrobras' leading role.

In its early stages, Petrobras adopted a passive strategy of adaption and diffusion of foreign technology, later moving to a more active and innovative strategy (Dantas and Bell, 2009). In 1963, the creation of the company's CENPES research center was a milestone in fostering in-house research, which was initially focused on the downstream sector (e.g., refining). In the wake of the 1973 oil crisis, the Brazilian government urged Petrobras to increase its investments in E&P in order to discover new reserves and ensure national energy security.[14]

The discovery of new offshore reserves in subsequent years encouraged Petrobras to create two internal divisions within CENPES dedicated to basic engineering and industrial research. Within this context, Petrobras intensified the network of collaboration with foreign suppliers to acquire and assimilate the technology embedded in imported equipment and services (Dantas and Bell, 2011).

In 1985, Petrobras launched the Technological Capability Development Program on Deep Water Production Systems (Procap), undertaken between 1986 and 1991 and involving 109 R&D projects. Total investments in Procap amounted to US$ 69 million, only 20% of which funded innovation projects (De Morais, 2013).

Procap was extended to a second phase, called Procap 2000, which aimed at developing technology to enable exploitation of underwater reserves at depths of up to 2000 m.[15] Procap 2000 was implemented between 1993 and 1999 at a total investment of US$ 90 million. The program consisted of 20 R&D projects developed by Petrobras in collaboration with 66 firms and 33 universities and research centers, thereby expanding the network of actors involved in technological development. In contrast with Procap, Procap 2000 assigned 80% of total investments to innovation (Freitas and Furtado, 2001; Ortiz Neto and Dalla Costa, 2007). The successful innovations achieved by the Procap 2000 allowed Petrobras to receive in 2001 the prestigious Offshore Technology Conference (OTC) award for the second time.

The introduction of the R&D clause in 1998 prompted three major changes in the technological strategy of Petrobras. First, the company's R&D investments rose at a compound annual growth rate of 11.7% between 1999 and 2015, reaching a staggering US$ 1454 million in 2011 (Fig. 1).[16]

On average, R&D investments undertaken by Petrobras in compliance with the R&D clause constituted 45% of the company's total R&D investments in 1998–2015, a strikingly high percentage. In short, this intensity boosted R&D investments to the discovery of huge offshore deep and ultra-deep-water reserves in the pre-salt area, which itself prompted new technological challenges. The favorable context of international oil prices occurring after 2001 should not be underestimated.

The boom in Petrobras' R&D investments involved a major expansion of its R&D center. In 2010, the company extended CENPES to twice its original size, adding pilot plants and modern labs and equipment. The number of researchers employed by CENPES rose from 1142 to 1775 between 2001 and 2016.[17]

Second, the expansion of R&D by Petrobras has been supported by a strengthened network of collaboration with STOs, based on two initiatives. On the one hand, Petrobras created a new internal division within CENPES dedicated to cooperation with STOs. On the other, in

[13] Data sorted by concessionaire.
[14] Between 1971 and 1981, Petrobras' investments in E&P rose from 26% to a staggering 89% of its total investments. Source: authors' calculation based on Petrobras data.
[15] In 1996, Petrobras discovered Roncador, the first oil field in ultra-deep water (1853 m).
[16] Petrobras has shown notably high R&D intensity: in 1999–2015, its R&D investments were on average a 0.75% of the company's sales. Source: Petrobras annual reports.
[17] Source: Petrobras.

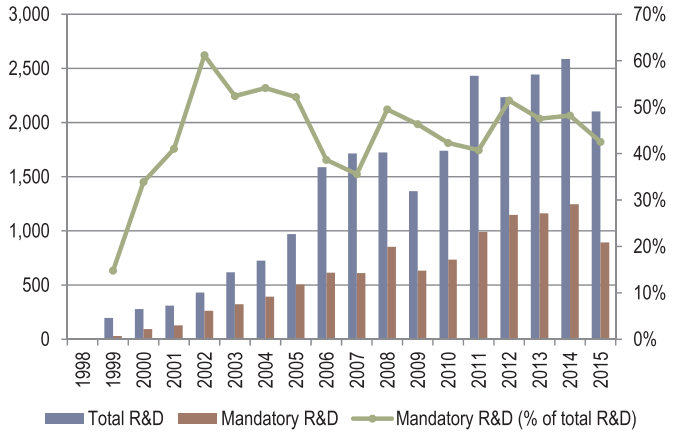

Fig. 1. Petrobras' total R&D investments versus Petrobras' mandatory investments in compliance with the R&D clause, in millions of BRL and as a percentage of total R&D investments. Notes: 1) In order to compare total R&D investments and mandatory R&D investments, we have converted the former from US$ to BRL using historical series from the Central Bank of Brazil; 2) data on total R&D investments for 1998 are not available.
Source: our elaboration based on data from annual reports of Petrobras and the database on R&D investments of ANP available online.

2006 the company launched the Thematic Network project, with a total investment of BRL 460 million through 2011 (De Morais and Turchi, 2013). The Thematic Network consists of 49 lines of scientific collaboration between Petrobras and domestic STOs related to areas of strategic interest to the company, including exploration, production, supply, and technological management. The Network was partly funded by the R&D clause, although the exact amount is unclear, this data being protected by confidentiality. Ferreira and Ramos (2017) argue the R&D clause has been crucial to the development of the Thematic Network, contributing to an open innovation approach that is more coherent with the technological challenges of pre-salt reserves. CENPES coordinates these networks and maintains continuous communications with all members to ensure cooperation. Until 2013, more than 70 STOs were involved in the Thematic Network (De Morais and Turchi, 2016). On average, there are 15 STO researchers for every Petrobras researcher involved (Fagundes Netto, 2014).

In 2000, the Procap 2000 program was extended into a third phase, Procap 3000, which aimed at enabling the exploitation of underwater oil fields at depths of up to 3000 m. Procap 3000 received an investment of US$ 128 million over ten years (De Morais, 2013). Within this program, CENPES signed 802 research cooperation agreements with 58 STOs and with 119 firms (De Morais and Turchi, 2016). In 2014, CENPES counted 1145 agreements on scientific collaboration with domestic STOs, plus 173 similar contracts with foreign STOs (Petrobras, 2015a).

Third, the expansion of Petrobras' R&D activity boosted the number of patents filed by the company at the National Institute of Industrial Property (INPI) (Fig. 2). Following the implementation of Procap, the number of patents grew steadily. However, Procap was dedicated mainly to adaptation of foreign technologies; later, when Petrobras began to target innovation through Procap 2000, it appears that patenting met with greater difficulty. On the other hand, during the application of the R&D clause − which coincided with the boom in R&D investments − the number of patents deposited by Petrobras soared to record levels. Still, we have been unable to determine the exact number of patents resulting from research projects funded by the R&D clause, due to data confidentiality.

In 2015, Petrobras received for the third time the Distinguished Achievement Award from the OTC for several innovations applied to ultra-deep-water E&P. One telling innovation was the Steel Lazy Wave Riser (SLWR). This was the first steel riser of its category in the world

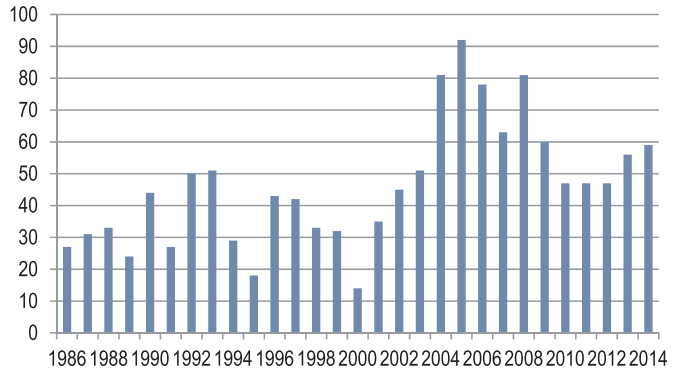

Fig. 2. Number of patents deposited by Petrobras at the INPI.
Source: our elaboration based on the industrial property database of INPI available online.

that connected to a Floating Production, Storage and Offloading (FPSO) unit, with spread mooring designed to resist the motion of the floating vessel in the harsh conditions of the pre-salt area.

The innovations implemented by Petrobras have allowed the company to reduce the drilling and completion time of oil wells in the pre-salt area from 310 days (before 2010) to just 89 days (in 2016) – a drop of 71% (Rocha, 2016). Moreover, Petrobras' technological advances allowed a sizeable cost reduction of around US$ 1 billion between 2013 and 2015 (Petrobras, 2015b).

3.2. Private firms

The R&D clause has affected the strategy of private firms in the Brazilian oil sector. On the one hand, IOCs have been forced to invest in R&D, but their financial contributions have been marginal in comparison with Petrobras' investments, as discussed in Section 2. Most R&D investments by IOCs have been allocated to projects undertaken by STOs. As we shall demonstrate, the interaction between IOCs and STOs is newly emerging, whereas relations between Petrobras and STOs have been consolidating for decades.

On the other hand, service companies have also been involved in the R&D clause as recipients of investments. Though the share they have received through the clause is minor, their participation in technological development has been mounting throughout the clause's implementation period. One compelling result is that, since 2010, world-leading services companies have opened new R&D centers in the Technological Park at the Federal University of Rio de Janeiro (UFRJ), located less than three kilometers from CENPES.

Drawing on interviews, we identified two factors that have motivated service companies to set up research centers in Brazil. First, firms have invested with the purpose of becoming involved and benefiting from the R&D scheme. Service companies sought to receive funding from oil companies to develop joint research projects, in particular with Petrobras, which has accumulated considerable knowledge in deep-water E&P. The proximity of the service companies' research centers to CENPES was seen as a positive factor in enhancing reciprocal collaboration. Second, service companies aimed at tapping into new opportunities in the supply of high-tech oilfield equipment and services for E&P in the pre-salt area.

The establishment of R&D centers in the Technological Park has generated new investments and employment in several areas related to E&P (Table 3). These companies receive subsidies in the form of low rental prices for the research locations as well as a reduced local tax rate on the research activities conducted.[18] However, our informants did not consider these incentives as major factors for investments in the

[18] See Law 5344/2011 of Rio de Janeiro city council, which establishes incentives to R&D investments in the Technological Park at the Federal University of Rio de Janeiro.

Table 3
R&D centers established by service companies in Brazil.
Source: our elaboration based on interviews with key informants and corporate information, updated to November 2017.

Company	Opening date	Investments (in millions)	Employees (No.)	Activities	R&D centers in other countries
Schlumberger	11/2010	BRL 50	300	Geo-engineering; fluid and rock tests; seismic-to-simulation software; seismic data integration-optimized solutions (pre-salt)	Norway; Russia; Saudi Arabia; United Kingdom; United States
Baker Hughes	10/2011	US$ 30	100	Reservoir characterization (pre-salt)	Germany; Malaysia; Russia; Saudi Arabia; United Kingdom; United States
FMC Technologies	01/2012	BRL 70	300	Sub-sea equipment for offshore E&P (pre-salt)	Belgium; China; France; India; United States
Halliburton	06/2013	BRL 26	100	Reservoir characterization; well engineering; flow assurance (pre-salt)	India; United Kingdom; United States
Vallourec	07/2013	BRL 90[a]	20	Steel pipelines for offshore E&P; automotive sector	France; Germany; United States
Chemtech[b]	01/2014	BRL 50	600	Basic engineering for offshore E&P (pre-salt)	China; Denmark; Germany; Turkey; United Kingdom; United States
Tenaris	04/2014	US$ 39	30	Test of connection pipelines; testing and qualification of new products for offshore E&P	Argentina; Italy; Japan; Mexico
EMC	05/2014	BRL 100[c]	80	Big data and IT solutions for offshore E&P (acquisition, analysis and visualization of engineering, geological and geo-physical data)	China; France; Holland; India; Ireland; Israel; Russia; Singapore; United States
General Electric	11/2014	US$ 1000[d]	160	Oil sector (offshore E&P, sub-sea processing and electrification, drilling, pipelines, and flow assurance); aviation; rail transports; health; energy and mining	China; Germany; India; United States
BG (Shell)[e]	2017[f]	US$ 1500–2000[g]	100[h]	Offshore E&P (pre-salt)	United Kingdom

Notes: .
[a] This refers to a period of five years and includes investments in the R&D center at Belo Horizonte (Brazil). The R&D center in Belo Horizonte was established in the 1960s where the company has its original headquarters.
[b] Chemtech was acquired by the Siemens group.
[c] This refers to the period 2014–2016.
[d] The value consisted of US$ 500 million in 2014, plus an additional US$ 500 million in 2015–2020.
[e] BG was acquired by Shell in 2016.
[f] Estimated value.
[g] Until 2025.
[h] Expected by 2020.

R&D centers. Firms must comply with a mandatory requirement to invest in a joint research project with the UFRJ[19] – indeed, all these companies have begun to cooperate with academia. However, this collaboration mainly consists in the funding of traineeships for students; moreover, two large firms, Schlumberger and Baker Hughes, are not legally bound to the investment requirement. Most importantly, R&D occurs within the firms, in that the research centers do not admit external researchers, even those from partner universities.

Furthermore, service companies have not undertaken any research projects with the technology-based firms (e.g., starts-up and spin-offs) incubated at the UFRJ that operate in the oil sector. These firms are strongly innovation-oriented, and their participation in joint research projects with service companies could constitute a powerful channel for fostering domestic technological development.

In this regard, in 2016, the ANP created the Scientific and Technical Committee (Comtec), a collective body constituted by representatives from the regulatory agency, the oil companies, and STOs. As Comtec is mandated to establish the guidelines for implementation of the R&D clause, it is highly recommendable that the committee addresses the participation of technology-based firms.

In compliance with the R&D clause, Petrobras invested in joint research projects together with service companies, which fostered technological innovations for deep-water E&P. A striking case of radical innovation is the Oil-Water Separation System (SSAO), developed by Petrobras in collaboration with the service company FMC Technologies. The SSAO is sophisticated sub-sea equipment that enables the separation of oil and water extracted from deep-water reservoirs. Installation of the SSAO in the seabed allows for considerable cost reduction versus topside equipment.[20] CENPES played a leading role in the project thanks to its substantial knowledge of E&P in deep and ultra-deep waters. The SSAO was manufactured in Brazil.

It is noteworthy that FMC Technologies retained full ownership of the patent for the SSAO. Indeed, based on interviews, we found that such intellectual property is a strategic asset for service companies as they aim to commercialize the patent, whereas oil companies are more interested in the use of the patented technology. The regulator attempted to address this issue in the ANP technical regulation 3/2015, which entered into force in 2016. The new regulation establishes clearly defined percentages of intellectual property rights on the intangible assets derived by projects funded by the R&D clause, to be assigned according to the effective contribution of each entity involved in the research. Should an oil company co-execute a project with a small service company, or with an STO, the latter are entitled to at least 50% of property rights. On the other hand, when the service company is a larger firm, the share of property rights should be negotiated among the parties involved. Therefore, the allocation of patents will be ultimately determined by respective bargaining power, as our interviewees suggested.

Intellectual property rights are of utmost relevance for service companies. Data published by the INPI reveal that service companies greatly increased their filing of patents just prior to the establishment of R&D centers in Brazil (Table 4). Our interviewees confirmed that the number of patents deposited does not necessarily reflect the implementation of new technologies but rather, and more importantly, the strategy to hamper competitors prior to their expansion into the country. As we shall explain, intellectual property rights also play a leading role in fostering technological development in the STOs.

Another telling case is the Enhance Vertical Deepwater Tree (EVDT), a subsea device for deep-water E&P jointly developed by Shell and FMC Technologies. The EVDT is an upgrade of previous equipment used in the Parque das Conchas oilfields, adapted to the conditions of Salema and Bjuiprá oilfields. The major progress of EVDT consists in the easy installation for E&P at water depths of up to 3000 m. The collector may be installed directly on the wellhead, which allows for faster well completion compared to the prior design. The EVDT allows a 20% reduction in production costs and a 15% reduction in delivery time, thus increasing profitability. The equipment was built in Brazil with 100% local content and its patent was exploited to manufacture the EVDT abroad and to deploy it in offshore E&P in Mexico and Malaysia. The EVDT was awarded the OTC New Technology Award and the ANP prize for technological innovation.

Finally, we found that service companies with research centers in Brazil had not yet exported any product manufactured in Brazil from patents initiated through research projects funded by the R&D clause. Achievement of this result may require a longer research period than has so far been observed.

3.3. Universities and research centers

In Section 3 we observed that, in compliance with the R&D clause, oil companies must invest at least 50% of the obligation in research projects undertaken by STOs. Table 5 shows the total investment received by the STOs involved in the R&D clause, which amounted to over BRL 4643 million in 2006–2015. In total, the clause funded 1361 projects carried out by 131 different organizations, of which 64 were public universities.

A considerable share of investments received by STOs was assigned to fund the construction, reform, or expansion of physical infrastructure for scientific purposes, such as buildings, labs, equipment, and materials. Data from the ANP show that 948 of the 1361 projects undertaken by STOs were related to scientific infrastructure, for a total amount of BRL 2238 million, corresponding to 48.4% of total investments received by these organizations. It is noteworthy that Petrobras funded around 95% of those investments. Moreover, investments in scientific infrastructure were higher during the early years of application of the R&D clause; in 2006–2009, on average, these investments represented around 79.6% of total investments received by STOs via the clause (Fig. 3). As our interviews revealed, this should be interpreted as the oil companies (mainly Petrobras) strategically opting for a strengthening of the physical infrastructure of the STOs prior to their investments in research.

The positive impact of the R&D clause on scientific infrastructures was supported by our respondents, in particular for those projects funded by Petrobras (Fig. 4). Through interviews, we found that the clause constituted a vital source of funding for Brazilian universities that, as interviewees suggested, have otherwise faced severe underfunding.

It should be considered that Petrobras had been cooperating with Brazilian STOs since long before the introduction of the R&D clause, which has thus served to reinforce prior relations (Ferreira and Ramos, 2017). However, the R&D clause has also managed to push other oil companies to invest in STO infrastructure, although contributions by these firms have been meagre compared to Petrobras' involvement.

One striking outcome revealed by our interviewees was that STOs benefited from full proprietorship of infrastructures funded via the R&D clause. Ownership of buildings, labs, and equipment will likely strengthen the capacities of those organizations.

Another major achievement of the R&D clause has been the promotion of scientific research, in several areas but mainly in E&P (Fig. 5). However, the biofuel sector has received only a minor share of resources, despite its being included in the ANP's mandate to foster technological development. Moreover, R&D in environment-related areas has been scant.

It is worth noting that 39% of total investments allocated to STOs (217 of 1361 projects) was assigned to programs devoted to the training of human resources: i) the Human Resources Program of the ANP (PRH-

[19] Mandatory requirements are expressed in a minimum amount of investments in a given period, as regulated by the agreement signed by each firm with the Technological Park.

[20] The SSAO received the New Technology Award from the OTC in 2012, and the ANP prize for technological innovation in 2013.

Table 4
Number of patents deposited at the INPI by service companies (1998–2014).
Source: our elaboration based on the industrial property database of INPI available online.

Company	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	*Total*
Halliburton[a]	15	12	19	31	28	54	35	41	21	26	41	41	68	111	243	154	89	*1999*
General Electric[c]	0	0	4	5	8	14	2	7	7	9	9	34	26	57	41	15	2	*1953*
Baker Hughes[b]	1	2	3	9	9	17	17	17	21	32	65	101	156	156	120	86	69	*1285*
Schlumberger	5	17	30	24	26	22	17	14	10	3	1	3	0	2	1	19	20	*377*
Vallourec	1	0	0	3	0	0	2	3	1	0	3	5	6	6	4	5	5	*166*
FMC Technologies	0	0	5	9	2	2	2	6	3	1	12	3	2	1	4	3	7	*116*
Chemtech	6	7	7	3	3	3	5	1	8	6	2	4	3	9	1	6	6	*80*
Tenaris	0	0	0	0	0	4	2	0	4	2	8	2	3	4	3	2	3	*37*
BG	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*4*
EMC	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	*2*
Total	*28*	*42*	*68*	*84*	*76*	*117*	*82*	*89*	*75*	*79*	*141*	*193*	*264*	*346*	*417*	*290*	*202*	*6019*
Petrobras	11	15	11	11	10	17	15	18	20	10	14	13	7	7	11	7	4	*921*

Notes: .
[a] Includes Welldynamics.
[b] Includes BJ Services.
[c] Includes Vetco Gray and ABB Offshore.

Table 5
Total R&D investments received by STOs via the R&D clause (2006–2015).
Source: our elaboration based on data from the database on R&D investments of ANP available online.

Receiving STO	No. of projects	Investments (millions of BRL)	% of total investments
Federal University of Rio de Janeiro (UFRJ)	259	517.78	11.2
Federal University of Pernambuco (UFPE)	37	161.23	3.5
Pontifical Catholic University of Rio de Janeiro (PUC-Rio)	57	157.59	3.4
Federal University of Santa Catarina (UFSC)	44	124.11	2.7
State University of Campinas (UNICAMP)	72	123.50	2.7
Federal University of Rio Grande do Norte (UFRN)	71	114.04	2.5
Federal University of Rio Grande do Sul (UFRGS)	72	102.90	2.2
University of São Paulo (USP)	67	96.82	2.1
Fluminense Federal University (UFF)	25	78.01	1.7
Almirante Paulo Moreira Institute of Ocean Studies (IEAPM)[a]	2	73.88	1.6
Federal University of Sergipe (UFS)	20	57.78	1.2
Federal University of Espírito Santo (UFES)	21	57.59	1.2
Federal University of São Carlos (UFSCar)	22	54.36	1.2
State University of Rio de Janeiro (UERJ)	27	52.33	1.1
Federal University of Bahia (UFBA)	37	51.84	1.1
Institute for Technological Research (IPT), São Paulo	16	49.39	1.1
Admiral Braz de Aguiar Instruction Center (CIABA)[a]	1	47.88	1.0
National Institute of Technology (INT)	15	43.23	0.9
University of Brasilia (UnB)	21	38.70	0.8
Instruction Center Admiral Graça Aranha (CIAGA)[a]	2	36.28	0.8
State University of Norte Fluminense (UENF)	22	33.59	0.7
Federal University of Ceará (UFC)	28	31.94	0.7
Federal University of Technology of Paraná (UTFPR)	12	12.61	0.3
State University of Minas Gerais (UEM)	5	3.47	0.1
National Institute of Technology (INT), PUC-Rio	1	3.27	0.1
Tiradentes University (ITP)	4	3.16	0.1
National Service of Industrial Learning (SENAI)[b]	2	2.79	0.1
LACTEC Institute	2	1.85	0.0
Federal University of Pará (UFPA); UFRJ; UERJ; Prooceano	1	1.59	0.0
Other organizations (of which):	393	2161.55	46.5
- Science without Borders	22	869.71	18.7
- PRH-ANP[c]	183	505.77	10.9
- Human resources (unspecified)	9	30.73	0.7
- Various organizations	179	755.33	16.3
Prominp (PNQP)[d]	3	348.72	7.5
Total	*1361*	*4643.76*	*100*

Notes: .
[a] Belongs to the Brazilian Navy. All projects undertaken by IEAPM, CIABA, and CIAGA have been financed by Petrobras.
[b] SENAI of the state of Santa Catarina.
[c] Human Resources Program of the ANP.
[d] The PNQP is the National Plan of Professional Qualification, which supports the professional qualification of human resources in the oil sector. The PNQP was funded by Petrobras in the framework of the Program of Mobilization of the National Oil and Natural Gas Industry (Prominp).

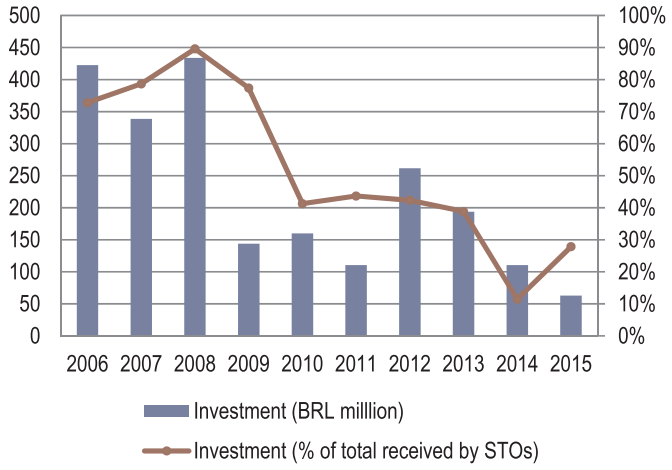

Fig. 3. Investments in physical infrastructure received by STOs via the R&D clause, in millions of BRL and as a percentage of total investments received by STOs.
Source: our elaboration based on data from the database on R&D investments of ANP available online.

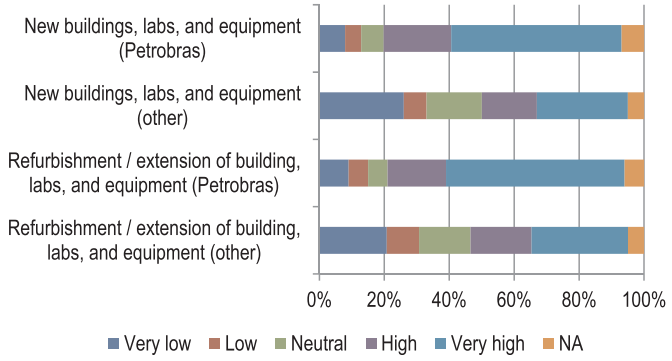

Fig. 4. Assessment of investments in infrastructure received by STOs via the R&D clause, percentage of total answers.
Source: our elaboration based on questionnaire to project coordinators.

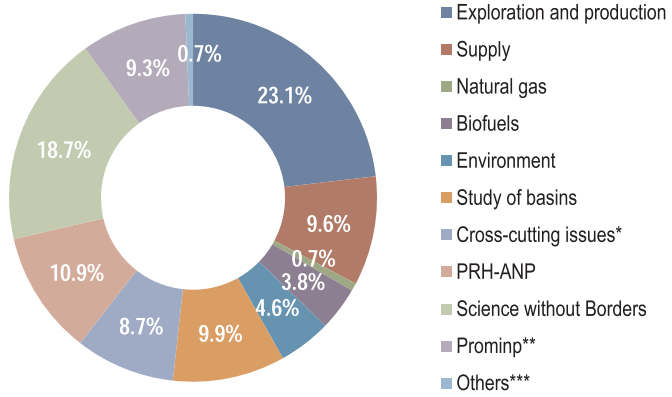

Fig. 5. Activities financed by the R&D clause undertaken by STOs (2006-June 2016), as a percentage of total investments received by STOs. Notes: * Includes a group of projects related with physical infrastructure (e.g. labs). * * Prominp is the Program of Mobilization of the National Oil and Natural Gas Industry. This data includes the investments assigned to the National Plan of Professional Qualification (PNQP), to the Instruction Center Admiral Graça Aranha (CIAGA), and to the Admiral Braz de Aguiar Instruction Center (CIABA). This includes investments in scientific labs of BRL 66.39 million. For this reason, the percentage indicated here does not correspond to that in Table 5. * ** Includes investments in scientific labs of BRL 14.97 million.
Source: ANP, 2016. *Boletim ANP Petróleo e P&D*, 36, August 2016.

Table 6
Investments generated by the R&D clause into Science without Borders (2006–2015).
Source: our elaboration based on the database on R&D investments of ANP available online.

Company	Receiving STOs	Projects (No.)	Investments (millions of BRL)
Petrobras	Unspecified organizations	2	742.97
BG	UFRGS	2	12.67
	UFRJ	2	11.33
	UNICAMP	2	6.61
	UFSC	1	15.81
	PUC-RIO	1	11.22
	USP	1	10.77
	UFRJ/UNICAMP	1	4.65
	UFRN	1	3.57
	Unspecified organizations	1	9.46
Statoil	Unspecified organizations	1	19.21
	UFSC	1	3.82
Shell	Unspecified organizations	1	9.49
Petrogal	Unspecified organizations	1	9.00

ANP); ii) Science without Borders; and iii) the Program of Mobilization of the National Oil and Natural Gas Industry (Prominp).[21] The PRH-ANP program was created in 1999 by the regulator with the aim of giving financial support to university students involved in scientific areas related with the oil, gas, and biofuel sectors. Between 2006 and 2015, the PRH-ANP received BRL 505.77 million via the R&D clause, fully funded by Petrobras. These resources were assigned to 183 projects of human resources training, undertaken by 34 universities (BRL 307.84 million) and by 19 research centers (BRL 197.33 million).[22]

Science without Borders was launched in 2011 by the Ministry of Education and the Ministry of Science, Technology and Innovation, in order to fund scholarships abroad for university students. This initiative received BRL 869.71 million via the R&D clause, funding 22 projects at eight Brazilian universities (Table 6).

The Prominp was established in 2003 at the initiative of the national government, to enhance the training of human resources in the oil sector.[23] The program received BRL 348.72 million, funded by Petrobras via the R&D clause, which benefited three projects developed by several STOs.[24]

In sum, a large share of investments generated by the R&D clause was assigned to the training of human resources. Although Petrobras was the largest contributor, the clause prompted other oil companies to fund this crucial activity for technological development.[25]

It appears that the investments generated by the R&D clause were paramount to fostering the training of human resources (Fig. 6). The projects undertaken by STOs may have contributed to enhancing the skills and capabilities of the researchers involved. It also appears that the research teams have developed networks with other similar groups. Moreover, our results suggest the research projects promoted both the hiring of new researchers and the stays of researchers already involved. Finally, funding from the R&D clause appears to have supported the participation of researchers in scientific events such as conferences.

Research projects funded by the R&D clause have apparently boosted scientific publications; our respondents agree these projects

[21] In addition to those three programs, the R&D clause has funded nine additional projects of training of human resources (BRL 2.1 million).
[22] Source: ANP.
[23] See: Decree No. 4925/2003.
[24] Source: ANP.
[25] See annex for additional comments from our respondents.

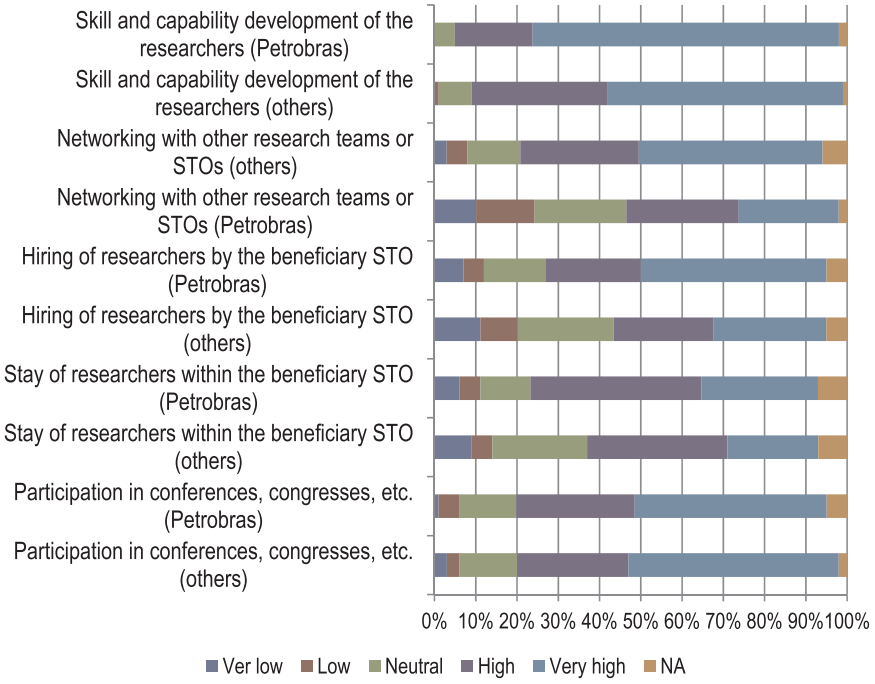

Fig. 6. Assessment of the investments in human resources received by STOs via the R&D clause, percentage of total answers.
Source: our elaboration based on questionnaire to project coordinators.

prompted new academic dissertations (82% of total answers for Petrobras projects, 76% for other companies), along with the publication of papers in international journals (74% of total answers for Petrobras projects, 72% for other companies).

A crucial finding of our research is that the R&D clause has apparently fostered innovation. A large share of respondents agree that projects funded through the clause favored the deployment of new or improved products (57% of total answers for Petrobras projects, 59% for other companies), as well as new or improved processes (58% of total answers, both for Petrobras and other companies).

One striking innovation generated by an R&D clause-funded project is the Buoy Supporting Riser (BSR). The BSR is a type of buoy that prevents movements by the floating platform used in offshore E&P from being transferred to the risers, thereby reducing the potential damage caused by fatigue and increasing the useful life cycle. The BSR project is an illustrative case of how the R&D clause has promoted "open" innovation, as several actors were involved: Petrobras, the service company Subsea7, the "Coppe" Institute at the UFRJ, and the Institute for Technological Research (IPT). Through our interviews, we found that coordination across all these actors was crucial, with Petrobras taking a leading role in each stage of the process.

A research project funded by Petrobras and developed at the PUC-Rio University resulted in the creation of the Direct Wire Optical Supervision System, known as MODA. MODA is a real-time surveillance system that identifies in advance, through optical fiber sensors, the occurrence and propagation of structural damage along the subsea risers. The system allows the monitoring of production to avoid losses due to damages, which may ultimately result in huge economic losses. It is noteworthy that the MODA was patented by Petrobras; however, the company licensed the technology to the academic research group at PUC-Rio, which established a technology-based firm, Monflex, to commercialize the patent. Our informants pointed out two factors behind this innovation: i) constant interaction with Petrobras during the research phase; and ii) access to intellectual property, which was *conditio sine qua non* to exploiting the invention and to establishing a spin-off.

Indeed, as previously observed, intellectual property rights play a critical role in the oil sector. In the absence of data from the ANP, the

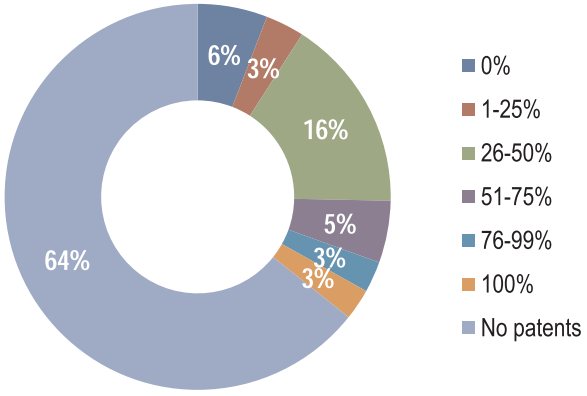

Fig. 7. Percentage of patent rights assigned to the STOs, percentage of total answers.
Source: our elaboration based on questionnaire to project coordinators.

findings of our survey suggest that 64% of the projects undertaken by STOs via R&D clause produced no patents. Moreover, where patents were filed, STOs received the majority of intellectual property rights in few cases (Fig. 7). This is partially due to the large share of investments in infrastructure and training; however, based on interviews, we found that, although the research projects were executed by STOs, oil companies exerted powerful influence to veto the patenting of project results and to obtain a large share of patent rights.

A major finding of our survey is that 81% of respondents considered that projects funded via the R&D clause have not promoted the creation of new technology-based firms. Interviewees revealed that these firms have yet to confront two obstacles. As mentioned above, researchers from the STOs must negotiate with the oil companies over patenting and ownership. Our informants suggest that many STOs do not have the technical capacity needed to negotiate with oil companies, or the administrative structure required to properly manage patents deposited by their researchers.

However, the R&D clause generates a powerful conflict of interest between STOs and existent technology-based firms. Many STOs provide

contracted services to oil companies in several business areas where those firms operate, and they are usually small companies managed by recent university graduates. Our informants from technology-based firms demanded greater financial support from the government to tap into high-tech activities, and to compete with service companies. In this regard, in 2015 the ANP revised the regulatory framework of the R&D clause to force oil companies to invest more in joint research projects with technology-based firms.[26] However, the new regulation does not address the conflict of interest or the financial needs of small technology-based firms; further research is needed to assess its impacts.

4. Conclusions

Our study has investigated the technological development process in the Brazilian oil sector during the period 1998–2015. We examined the effects of a mandatory contractual clause that forces oil companies to invest 1% of gross revenues from large oilfields into R&D. The following conclusions can be drawn.

i) Although the R&D clause is a novelty in Brazilian regulation, it does not constitute a stand-alone instrument in terms of research policy in the oil sector. The adoption of the R&D clause should be considered within the historical path of Petrobras' technological strategy. Still, implementation of the clause has entailed a major expansion of R&D investments. In this regard, the clause operates as an instrument to regulate the process of technological development that was already ongoing under the leadership of Petrobras. In order to encourage the break-up of the monopoly in the oil sector, the R&D clause was considered an instrument to enhance the participation of new actors in technological development. As oil production in the pre-salt area is expected to increase, with greater contributions through the R&D clause from oilfields regulated by production-sharing agreements, further research is needed to investigate whether the impacts of the clause differ according to different types of contractual regimes.

ii) The R&D clause, together with prior initiatives such as the Procap, constitutes a resolute governmental strategy – as suggested by Sabato and Botana (1970) – which aims to foster technological development over a lengthy trajectory. Although at early stages technological development was mainly confined to the adaptation of foreign technology, especially before the adoption of Procap 2000, endogenous innovation gained momentum in recent years to enable the exploitation of the large offshore reserves.

iii) From the perspective of the actors involved in technological development, the R&D clause has fostered the incorporation of new players, though it has been unable to challenge the leadership of Petrobras. The state-owned company was constrained from access to leading technological capabilities in its early stages. However, Petrobras has been constantly adapting its strategy over time, to make feasible the exploitation of new oil discoveries, and this has resulted in progressive technological leadership in deep-water and ultra-deep-water E&P.

The incursion of leading-edge service companies and the participation of research centers bolstered the network of actors that contribute to fostering research, innovation, and diffusion of new technologies across the economy, as suggested by the national innovation system approach. However, it appears that a reverse technological transfer has also occurred, where Petrobras has transmitted its knowledge on deep-water E&P to service companies via joint research projects.

The implementation of the R&D clause coincided with the break-up of the state monopoly, which meanwhile favored the engagement of oil companies in technological development. Although the participation of these companies in the R&D clause fostered research, their investments have so far been relatively limited, as has their overall contribution to fostering the network of actors. Moreover, from our results it appears that, although the R&D secured stronger coordination across actors, the collaboration between Petrobras and STOs is deeper than that occurring between other oil companies and STOs, the state-owned company having nurtured its partnership with universities for a longer time.

iv) Our findings suggest the R&D clause boosted innovation, which has enabled the Brazilian upstream oil sector to attain world-class leading-edge technology. However, this process may face two challenges in the near future.

First, the R&D clause should not be considered a panacea in terms of fostering innovation; greater integration of the R&D clause into industrial policy is needed for spreading innovation from the oil sector to the rest of the economy. Moreover, it is noteworthy that the amount of investments generated by the R&D clause has been affected by fluctuations in oil prices, as these influence the value of gross revenues, which serve as the basis for calculation of the 1% rule. Second, intellectual property rights may frustrate the deployment of new technologies, especially by STOs and small technology-based firms, which face strong asymmetries of power vis-à-vis oil companies. Greater public support to STOs is needed to strengthen their technical and administrative capacities to manage property rights. As explained above, the ANP has recently approved a new regulatory framework to address this concern. Therefore, further research is needed to investigate the impacts of the new regulation on the assignment of intellectual property rights. Moreover, greater investigation is needed to assess whether and why some STOs are more successful in fostering innovation and patents than others, in order to support policy decisions.

Along with these achievements, the R&D clause faces several limitations, which should be duly considered by other countries pursuing the adoption of a similar institution.

i) Apart from Petrobras, the R&D clause has failed to bring together oil companies and service companies, except for very few cases such as the EVDT. The former have mostly funded projects undertaken by STOs; simultaneously, the strategy of the service companies has been primarily focused on cooperating with Petrobras. Considering the interrelation between the technological strategies of oil companies and service companies, greater cooperation between the two sides is needed to boost technological development. In this regard, the newly established Comtec may serve as a platform to foster this collaboration, as well as to ensure greater integration and coherence between R&D investments and national innovation policy. Coordination between the R&D clause and local-content requirements is also needed to foster the nexus between research, innovation, and productive linkages.

ii) Technology-based firms have so far played a minor role in the R&D clause scheme. The new regulatory framework aims at encouraging oil companies to invest in joint R&D projects with those firms. However, current legislation does not address the asymmetry of power between them, nor the conflict of interest between the technology-based firms and the STOs. Greater integration and coordination between the R&D clause and the national innovation policy is needed to foster the participation of technology-based firms in technological development.

[26] See ANP technical regulation 3/2015.

Appendix A

See Appendix Tables A1 and A2

Table A1
Distribution of the interviews.
Source: authors' elaboration.

Organization type	Name(s)	People interviewed (No.)
National oil company	Petrobras	8
Other oil companies	BG; Brasoil; Chevron; OGPar; Petrogal Brasil; Queiroz Galvão E&P; Repsol; Shell; Statoil	10
Service companies	Baker Hughes; Cameron (One Subsea); CGG; Chemtech (Siemens); EMC; FMC Technologies; Kongsberg Maritime; MEI Engenharia; SBM Offshore; Schlumberger; Technip; Tenaris; Transocean; Vallourec	19
Technology-based firms	Ambipetro; DPSGeo; ESSS; Hytron; Monflex; Oilfinder; Petrec	7
Regulator	ANP	3
Industrial associations	Agência de Inovação Inova UNICAMP; Associação Brasileira de Engenharia Industrial (ABEMI); Associação Brasileira de Máquinas e Equipamentos (ABIMAQ); Financiadora de Estudos e Projetos (Finep); Incubadora de Empresas Coppe UFRJ; Instituto Brasileiro de Petróleo, Gás natural e Biocombustíveis (IBP); Organização Nacional da Indústria do Petróleo (ONIP); Parque Tecnológico da Universidade Federal do Rio de Janeiro (PT-UFRJ); Serviço de Apoio às Micro e Pequenas Empresas (SEBRAE)	12
STOs	Federal University of Rio de Janeiro (UFRJ); Pontifical Catholic University of Rio de Janeiro Rio de Janeiro (PUC-Rio); State University of Campinas (UNICAMP); Federal University of Rio Grande do Norte (UFRN); Federal University of Rio Grande do Sul (UFRGS); University of São Paulo (USP); Fluminense Federal University (UFF)	14

Table A2
Selected open comments from survey respondents.
Source: questionnaires answered by project coordinators.

1. Investments generated by the R&D clause were absolutely essential for maintaining our academic studies.
2. Without Petrobras' support, the research in Brazilian universities would be substantially reduced.
3. The chance to install a new physical infrastructure funded by the R&D clause was crucial. Without that, there would be no research and development.
4. The impact of investment by oil companies in universities funded via the R&D clause was extremely important and substantial. That instrument provided the mechanism to build an adequate infrastructure by which to conduct research, as well as to train human resources.
5. The R&D clause and Petrobras' Thematic Network constitute excellent actions to foster integration between universities and the industrial sector to boost R&D. Research projects such as those funded by Petrobras are of utmost relevance for the universities, as they provide: opportunities to train research groups; increases in scientific publications; deeper integration across the researchers within an organization and between them and peers within other, similar entities; integration among researchers from different areas; modernization of labs; and more funding for research.

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