doi:10.12662/2359-618xregea.v7i1.p44-59.2018

ARTIGOS

AN EMPIRICAL STUDY OF PROCESS INNOVATION IN AN R&D LABORATORY OF AN OIL & GAS COMPANY

ABSTRACT

The main goal of this paper was to study how process innovation development occurs in a successful oil and gas firm. We tried to reach this goal by means of a case-study analysis of a Brazilian multinational oil and gas company's R&D laboratory that is recognized as successful in innovating. This study analyzed the innovation development by investigating the strategic choices to develop process innovation and the appropriability mechanisms that allow the firm to benefit from the innovations. Concluding, we proposed a framework connecting the strategic choices and the appropriability mechanisms of the focused firm, which may be appropriate for oil and gas firms with similar overall strategies.

Keywords: Process Innovation. Appropriability. Oil and Gas Industry.

1 INTRODUCTION

Since the seminal work of Schumpeter (1934), innovation has been recognized by several authors as an option to improve the firm's performance (DECAROLIS; DEEDS, 1999; FAEMS; VAN LOOY; DEBACKERE, 2005), or a way to ensure the firm's survival in a globalized world, which is strongly competitive and with a high degree of uncertainty (TEECE, 2007). In order to succeed in innovation development, firms are investing increasingly in internal R&D. However, due to the increasing complexity and diversity of technologies nowadays, sometimes it becomes impossible for the firms to maintain a high innovation performance operating isolated.

Therefore, to compete in the technological frontier, besides investing in internal R&D, it is critical to search for external resources to ensure competitive advantage (CHESBROUGH, 2003). In this scenery, some companies achieve greater success in their efforts to innovate than others, both internally or through alliances (BAUM; COWAN; JONARD, 2014; HALL; BAGCHI-SEN, 2007). The success in developing innovations is even a bigger challenge for technology-based firms (BELDERBOS et al., 2010). Nevertheless, being innovative does not guarantee that

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the firm will profit from their innovations (TEECE, 1986), making necessary the adoption of successful appropriability strategies (COHEN; WALSH, 2001).

Several researchers have been studying the strategic choices adopted by firms that intend to innovate. These strategies involve decisions about choosing between radical and incremental innovation, creative destruction and learning-by-doing, exploration and exploitation, or internal and open innovation (CHENG; HUIZINGH, 2014; DU; LETEN; VANHAVERBEKE, 2014; LAURSEN; SALTER, 2006).

Product and marketing innovation have received more attention than process innovation. A quick search for "process innovation" in the Web of Science database (WEB OF SCIENCE, 2015) returned around 500 articles. When the search was made for "product innovation", around three times more articles (more than 1,500) were found. This is a small evidence that process innovation does not have as much attention as product innovation by the academy. However, process innovation has an important role to enhance productivity (ROCHINA-BARRACHINA; MAÑEZ; SANCHIS-LLOPIS, 2010), and may bring competitive advantage to companies, especially the ones that compete in an intensive capital industry. Process innovation also requires different management and commercialization strategies than product innovation (MAINE; LUBIK; GARNSEY, 2012), which justifies a specific focus.

This article seeks to fill this gap and contribute to the academy and to managers by answering the following questions: **Which strategies may an oil and gas firm adopt to improve its process innovation performance? Which mechanisms should it adopt to appropriate the benefits of the innovations developed?** We define a good process innovation performance as the systematic and successful "implementation of new or significantly improved production or delivery method." (ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, 2005, p. 50). In order to answer these questions, we conducted a case-study in an R&D laboratory of an important Brazilian oil and gas firm with recognized success in competing in the technological frontier, and collected data through in-depth interviews with key interviewees, which were triangulated with information from secondary data sources. Answering these questions, we aimed to make propositions that may be valid for firms of the same industry to be tested in future studies. The choice of an R&D lab as the unity of analysis is justified by Chesbrough, Vanhaverbeke and West (2006, p. 287), which stated that "the sub firm level of analysis is particularly salient in understanding the sources of innovation."

2 THEORETICAL REFERENCES

2.1 PROCESS INNOVATION

According to the OECD's Oslo Manual:

> Technological process innovation is the adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organization, or a combination of these changes, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products (ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, 2005, p. 32).

Tomlinson (2010) defined process innovation as the introduction of new equipment/technology or input material, organizational changes, or improvements in the production process. Process innovation may bring advantages for the firm in several ways. It may improve productivity (TERJESEN; PATEL, 2017), may enable cost reduction (PAULA; SILVA, 2017) by transforming fixed costs into variable costs (MOUTINHO et al., 2015), and is a type of innovation that is more difficult to imitate (PAULA; SILVA, 2017; PRAJOGO, 2016). Studying process innovation is important because this type of innovation requires different management and commercialization strategies compared to product innovation (MAINE; LUBIK; GARNSEY, 2012) and the literature about it is scarce (TERJESEN; PATEL, 2017). Maine, Lubik and Garnsey (2012) concluded that alliance-building capabilities, mainly on alliances with suppliers (HAGEDOORN, 1993), and experimentation are more important for process innovation than for product innovation. To succeed in developing process innovation, firms must invest intensively in R&D (TOMLINSON, 2010) and exploit the radical and generic nature of their technology (MAINE; LUBIK; GARNSEY, 2012).

2.2 INNOVATION STRATEGY

A good fit between the firms' innovation strategy and the business environment is vital for delivering a good performance (PRAJOGO, 2016). A firm's innovation strategy is composed of several strategic choices. Learning-by-doing versus creative destruction, exploration versus exploitation, flexibility versus a well-defined objective (FAEMS; VAN LOOY; DEBACKERE, 2005), internal versus open innovation (CHENG; HUIZINGH, 2014; DU; LETEN; VANHAVERBEKE, 2014; LAURSEN; SALTER, 2006), and radical versus incremental innovation are some of the strategic choices for innovation in development highlighted by the literature.

Learning-by-doing (ARROW, 1962) may induce the development of process innovation according to a trial and error dynamics, in a continuous improvement process (BOGERS, 2009) driven by experience and learning efforts (DOSI; GRAZZI; MATHEW, 2017). On the other hand, creative destruction is the concept of making an old technology obsolete by creating a new and superior innovation (SCHUMPETER, 1934).

According to March (1991, p. 71), exploration of new possibilities occurs by "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation." Exploitation of successes already developed is "refinement, choice, production, efficiency, selection, implementation, execution." (MARCH, 1991, p. 71). The firm should balance exploration and exploitation because exploitation has a better financial return in the short therm, but the absence of exploration may compromise the firm's survival in the long term (BELDERBOS et al., 2010; MARCH, 1991). The firm's engagement in both exploration and exploitation is called organizational ambidextry (KORYAK et al., 2018). According to the authors, top management team heterogeneity strongly contributes to exploration, exploitation, and ambidextry, while investments in R&D contributes only to exploration (KORYAK et al., 2018).

Another important choice for the innovating firm is between flexibility (GHEMAWAT, 1991 apud FAEMS; VAN LOOY; DEBACKERE, 2005), which allows fims to develop innovation and keep them as options opened; and innovating following a well-defined objective. Furthermore, firms may innovate with their own resources, with external resources or with a mix of both Chesbrough (2003, p. 24) introduced the concept of open innovation as "the use of internal and external flows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively." This concept claims that it is possible to develop and expand the markets of innovation through paths, ideas or resources that are not internal to the organizations, collaborating with performance. The effectiveness of open innovation was suported by several subsequent empirical studies (CHENG; HUIZINGH, 2014; DU; LETEN; VANHAVERBEKE, 2014; MARTINEZ et al., 2014). Open innovation may be addressed by strategic alliances, which are voluntary arrangements among organizations involving exchange, division or co-development of products, technologies or services (GULATI, 1998). These arrangements may be among the firm and various stakeholders such as customers, suppliers, competitors, universities, the Government, research institutes or several of them at the same time, forming an alliance portfolio. Several authors (BELDERBOS, CARREE; LOKSHIN, 2006; SEYFETTINOGLU; TASDOGAN, 2014) studied these various configurations empirically. Cohen and Levinthal (1990) highlighted that the success of partnerships, when the main goal is knowledge transfer and innovation development, is a function of the partners' absorptive capacity, which is "the ability of the firm to recognize the value of new external knowledge, assimilate it and apply it for commercial purposes." (COHEN; LEVINTHAL, 1990, p. 128). The authors proposed the existence of a positive relationship between absorptive capacity and internal R&D investments (COHEN; LEVINTHAL, 1990). Macedo-Soares, Barboza, and Paula (2016) proposed that the moderation role of absorptive capacity on the positive influence of alliance portfolios on innovation performance vary according to the alliance portfolio characteristics, notably the diversity of partners.

Dewar and Dutton (1986) categorized innovation as incremental when it is introduced into a product or process steadily and gradually, without radical changes. Radical innovation, on the other hand, happens when there is a change of paradigm and when this change promotes, through a technological evolution, the creation of a new set of attributes initially not appreciated by current customers, but that enable the firm to entry into new markets, acquiring new customers and offer new applications. Incremental and radical innovation, besides being from different natures, are affected by different internal firm's capabilities. Forés and Camisón (2016) showed that incremental innovation is positively influenced by internal knowledge accumulation capabilities and absorptive capacity, while radical innovation is mainly influenced by absorptive capacity. As absorptive capacity is associated with internal R&D, these findings suggest that the adoption of external knowledge from strategic alliances, which is potentialized by the absorptive capacity, is vital for radical innovation. On its turn, incremental innovation may be developed effectively by combining internal and external knowledge or making use only of internal knowledge.

2.3 APPROPRIABILITY OF INNOVATION BENEFITS

Appropriability mechanisms are means of a firm to protect innovation from imitation and try to ensure that it will earn an appropriate share of the rents generated by the innovation (COHEN; WALSH, 2001), which in other ways could go to imitators, suppliers, clients etc (TEECE, 1986). The appropriability regime, which is the set of mechanisms used by the firm, is even more important when the organization relies on strategic alliances, which raises misappropriation risks. The higher the risk of missappropriation, the more hierarchical the alliance governance is (GULATI; SINGH, 1998) and higher the coordination costs are.

According to Hurmelinna-Laukkanen and Puumalainen (2007), there are five types of appropriability mechanisms that may compound a firm's appropriability regime: i) nature of knowledge - codified and tacit; ii) institutional protection - IPRs (intelectual property regimes), contracts and labor legislation; iii) human resources management – communication, (im) mobility; iv) practical/technical means – passwords, secrecy, access restriction etc; and v) lead time – market entry, continuous development etc. From this list, institutional protection may be classified as a formal mechanism, while the others may be classified as informal mechanisms (HALL; SENA, 2017).

Each appropriability regime may bring different results depending on the strategic goals of the firm (HURMELINNA-LAUKKANEN; PUUMALAINEN, 2007). If the company has short-term goals, it should use lead-time and institutional protection. On the other hand, if it has long-term goals, it should use HRM and institutional protection. If the firm adopts a strategy of building barriers to competitors, it should use tacit knowledge and practical/ technical means (HURMELINNA-LAUKKANEN; PUUMALAINEN, 2007). Several other factors also influence how suitable each appropriability mechanism is: the industry, the country, the technological complexity, and the level of connections between the organizations involved (ALNUAIMI; GEORGE, 2016; HALL; SENA, 2017). According to Revilla and Fernández (2012), the usage of informal appropriability mechanisms (based on tacit knowledge and confidentiality) favors large companies.

In strategic alliances, there is a paradox between knowledge sharing and protection, as shared knowledge may be used both for cooperation and for competition by the same company. A perceived strong appropriability regime has a positive effect on innovation output (incremental or radical) in alliances with competitors (RITALA; HURMELINNA-LAUKKANEN, 2013). Also, exploitation alliances have a positive relationship with potential rent generation (long-term return), but a negative relashionship with rent appropriation (DURAND; BRUYAKA; MANAGEMATIN, 2008), corroborating the affirmative that the risk of misappropriation may drain the innovator's profits.

3 RESEARCH METHOD

The nature of this research is exploratory, with the intention to build theory and propositions using a grounded theory approach (STRAUSS; CORBIN, 1998) to inspire future studies. To achieve this goal, it is necessary to propose new variables and relationships, which justifies the choice of the case-study method (REDDY, 2015). Case studies are also indicated when the researcher is dealing with a poorly understood phenomenon (EISENHARDT, 1989).

An R&D lab of a Brazilian multinational oil and gas company was chosen due to its success in process innovation performance. The number of patents applied is a representative variable of the innovative success as it is a proxy frequently applied to represent the innovation performance construct (BABA; SHICHIJO; SEDITA, 2009; KIM, PARK; LEE, 2014). The lab was involved in obtaining over 50 patents during the last 20 years. In addition, it has a continuous process of developing innovations for the company.

The main data were obtained through three visits to the laboratory and in-depth interviews with three researchers (three interviews with each interviewee in a total of around six hours), which were recorded and transcripted. The first interview with each interviewee was open, allowing the researchers to capture more information to build a semi-structured questionnaire. The second interviews were conducted following the semi-structured questionary built based on theory, previous research from secondary data and on information obtained from the first open interview. The third visit was made to clarify some points that remained unclear. The main characteristics of the informants were described in Table 1. Documental research for validating and triangulating the information obtained from primary sources was also carried out. It consisted in accessing the company's homepage, internal documents, including the firm's 2014 and 2015 annual reports, and INPI's (Instituto Nacional de Propriedade Intelectual) patent database (INSTITUTO NACIONAL DA PESQUISA INDUSTRIAL, 2015). All the data collected were analyzed and triangulated with the support of inductive content analysis techniques (ELO; KYNGAS, 2008).

Table 1 - Informants' descriptions

	Informant 1	Informant 2	Informant 3
Years in the firm	36	28	12
Position	Chemical engineer	Chemistry technician	Chemistry technician
Own employee?	Yes	Yes	Yes
Number of patents	28	4	2

Source: elaborated by the authors.

Table 2 - Some patents developed by the studied lab

Deposit Date	Patent Title
16/04/2012	METHOD FOR OBTAINING GLYCERIN PHOSPHORIC ESTER, THE MOLHABILITY MODIFYING AGENT OBTAINED BY THE PROCESS AND ITS USES
04/09/2008	BIODIESEL PURIFICATION PROCESS
21/06/2007	CATALYTIC CRACKING PROCESS FOR PRODUCTION OF DIESEL FROM OILSEEDS
19/11/2004	COMBUSTIBLE MIX
30/11/2001	PROCESS FOR BIODIESEL PRODUCTION
12/12/2000	COMPOSITIONS FOR MARKING LIQUID PETROLEUM PRODUCTS AND ITS USES
15/02/2000	METHOD FOR APPLICATION OF FLUORESCEINE LIPOPHILIC ESTER AS A COLORIMETRIC TRACER OF PETROLEUM PRODUCTS
27/07/1999	APPLICATION OF INORGANIC SALTS OF PERSULFURIC ACID AS ACTIVATORS OF DELAYED ACTION FOR SGN REACTIONS
27/03/1998	SECONDARY OIL RECOVERY PROCESS WITH TREATED WATER INJECTION
17/10/1997	PROCESS FOR THE THERMO-HYDRAULIC CONTROL OF GAS HYDRATE
19/03/1997	ACTIVATORS OF DELAYED ACTION FOR NITROGEN GENERATOR SYSTEM
21/01/1997	THERMO-CHEMICAL PROCESS FOR DEPARAFFINATION OF EXPORT DUTS IN CONDITION OF PETROLEUM FLOW
28/12/1995	PROCESS OF FIXATION OF INCRUSTATION INHIBITOR IN SUBSTRATE FORMATIONS
29/11/1995	THERMO-CHEMICAL PROCESS FOR DEPARAFFINATION OF LARGE DIMENSIONS
22/11/1995	PROCESS OF PREPARATION OF ALIPHATIC POLYANIDHRIDS
15/10/1993	THERMO-CHEMICAL PROCESS OF CLEANING OF STORAGE TANKS
15/03/1993	THERMO-CHEMICAL PROCESS OF DEPARAFFINATION OF HYDROCARBON CONDUCTORS
24/08/1990	PROCESS OF DEPARAFFINATION OF PRODUCTION FORMATIONS
04/12/1987	PROCESS OF STIMULATION OF PRODUCTION FORMATIONS OF HYDROCARBONS
05/06/1987	CONTINUOUS HYDRAULIC FRACTURE PROCESS WITH FOAM
11/04/1986	PROCESS OF GALACTOMANNAN OBTAINING AND COMPOSITION FOR FORMATION FRACTURING FLUID
30/09/1983	PROCESS OF OBTAINING GALACTOMANNAN
10/05/1983	A GELEIFIED ACID FLUID COMPOSITION AND PROCESS FOR PREPARING A COMPOSITION
02/05/1983	MECHANICAL PROCESS OF OBTAINING GUM-GUAR
30/03/1983	PROCESS OF OBTAINING GUM-GUAR FROM BEAN-GUAR
27/04/1982	PROCESS FOR PREPARING A COMPLETING FLUID

Source: (INSTITUTO NACIONAL DA PESQUISA INDUSTRIAL, 2015, online).

4 RESULTS AND DISCUSSION

The company chosen is one of the biggest Brazilian firms. With more than 80.000 employees, it has upstream and downstream operations in the oil and gas sector in all states of Brazil and in more than 15 countries. The lab chosen is one of the most innovative among a big number of labs that also work with process innovation inside the firm.

According to internal documents, the lab has a staff of 89 professionals among own employees and outsourced workers. The mission of the laboratory is to create solutions to prevent obstruction of pipelines that transport oil from production fields located in deep-water to the storage and transport units. These solutions differ due to the characteristics of the produced oil, which requires a great deal of innovation. The lab has more than 50 developed and patented technologies. Table 2 shows a list of some patents developed by the lab. One example of patent is the Nitrogen Generator System (SGN), which is a thermo-chemical process for the dewaxing of oil export pipelines.

4.1 FLEXIBILITY VERSUS WELL-DEFINED OBJECTIVE

The company privileges the generation of innovation according to well-defined objectives. There is a committee in the firm top-

-management that defines the projects the company will focus, and the innovation efforts are directed to attend these previously determined goals. “We have a so-called technological organizational committee [...] in this committee, the design lines that we must follow to meet the great challenges of the company are defined [...] throughout the project, innovations appear.” (INFORMANT 2).

Although the firm has a hierarchical structure, sometimes there is a relaxation of the current hierarchy, with professionals from different areas working in a matrix structure for some projects, in order to facilitate the emergence of innovation. Nevertheless, this flexibility only exists to attend the previously well-defined objectives. It is not common to create innovations not planned as options for the future. “The matrix structure helps a lot that [...] in some projects, you forget the formal structure to make it happen fluidly, managers should have flexibility [...] management sponsorship.”(INFORMANT 1).

According to the affirmatives above, the conclusion is that innovations occur based on projects that follow a well-defined and rigid strategic plan. Any deviations from the plan are sent to the top-management for approval and, if approved, some strategic objectives should be formally changed in order to start efforts to develop the innovative idea. It is consistent with the affirmative that process innovation in the oil and gas industry is risky and has high development costs (OLIVEIRA, 2011). The company many times does not have the amount of money to invest in all the ideas that emerge or will have to stop another project to do so. Therefore, the development of process innovation that is not linked to the strategic plan of the company tends to generate expenses that will not pay off and is generally not prioritized.

Proposition 1 - A high level of process innovation performance achieved by an oil and gas firm might be strongly related to the level of alignment between the innovation efforts developed by their internal R&D and the organization’s strategic planning.

4.2 LEARNING-BY-DOING VERSUS CREATIVE DESTRUCTION

Both concepts occur in the lab: learning-by-doing and creative destruction. The company was a pioneer in deep-water exploration and the lab, to solve new types of problems, had to create new innovations, superior to the old ones, which made the latter ones become obsolete. These kinds of solutions may be sometimes radical innovation. The following part of the interview exemplifies it:

> It (the company) not only has solutions to problems worldwide as it also has some problems that it pioneered [...] for example, the dewaxing submarine pipeline in deep-water. There wasn´t this kind of problem, we opened this frontier [...] pioneering even in the problems, not only in the solutions (INFORMANT 2).

The following statement of an informant about the occurrence of learning-by-doing shows that this process of innovation development also occurs: “In fact, innovation and patents are a result of a research project or even a scientific technical assistance [...] to solve an emergency problem.”(INFORMANT 1).

As stated in the above discussion, learning-by-doing and creative destruction are not opposite strategies to developed process innovation. The innovative outcome may be achieved with both types and it is mandatory for all R&D labs to master both processes. Learning-by-doing is very important for the development of process innovation (PAULA; SILVA, 2017) and is usually first adopted. Quite often, during the learning-by-doing process, problems emerge that bring the necessity to generate an innovation that destroys the old solutions, in a creative destruction process. As affirmed by Dosi, Grazzi and Mathew (2017), learning-by-doing is driven by experience and learning efforts, which improves internal knowledge. Internal knowledge is necessary to increase absorptive capacity (COHEN; LEVINTHAL, 1990), which drives radical innovations (FORÉS; CAMISÓN, 2016). And creative destruction is a process started, by nature, by more radical innovations. Considering this, both ways of developing process innovation are complementary. Propositions 2a and 2b formalize the conclusions leaded by the discussion above.

Proposition 2a - A high level of process innovation performance achieved by an oil and gas firm might be strongly related to a high level of learning-by-doing developed by its internal R&D.

Proposition 2b - A high level of process innovation performance achieved by an oil and gas firm might be strongly related to a high level of creative destruction developed by its internal R&D.

4.3 INTERNAL R&D VS. STRATEGIC ALLIANCES

The company invests in internal R&D as its main strategy. All informants consider internal R&D strategic for the whole industry.

> Every dollar you spend in the research center turns to $100 [...] It is a feeling that you really win. Developing technology is an investment.
> All technologically based firm, if it has no proprietary technology in at least a few segments […] it suffers, it succumbs to others (companies) more robust (INFORMANT 3).

Nevertheless, we notice the existence of alliances with suppliers, rivals, universities, research institutes and other companies. Internal R&D favors a high level of innovation performance through alliances because it raises the absorptive capacity of the lab and of the firm. Alliances with universities and with research institutes usually happen when the company internally does not have the expertise to develop the necessary innovation and is typical of radical innovation (BABA; SHICHIJO; SEDITA, 2009). The declaration below exemplifies this fact: "COPPE / UFRJ has knowledge about heat transfer. Therefore, we made a contract with the institution to build a simulator that provides the temperature that SGN will reach in the pipeline. It was fostered by ANP (National Petroleum Agency)." (INFORMANT 1).

Cooperation with rivals is mainly used to share resources and costs. There is a major concern with misappropriation and, on account of that, there are complex legal mechanisms to protect the innovations. These alliances are generally formed as joint ventures (JVs).

> Generally, JVs between two oil companies […] they seek to collaborate with that theme, without necessarily generating a patent [...] for example, our company has a waxing problem in production risers in deep-water. A rival company also has (the same problem) [...] they identify it as a common problem of the industry.
> We have a common problem; we make a technological cooperation agreement where companies exhibit what they have on that particular subject and create the scope of a joint project. The goal is the final solution [...] each company goes to one side and from the final solution, both (companies) will benefit from the result that each has developed [...] it is shared, patented together (INFORMANT 2).

Collaboration with suppliers exists, which corroborates with the affirmative that this kind of alliance is the most common in process innovation.

> In such cases there is a nondisclosure agreement[...] it (the product) will leave the industrial installation (of the supplier) with the name (of the focal company) [...] it is called provision of chemical service.
> Our company worked hard to build offshore remote units. You don´t have people living on the platform, only commands. For it, we counted on IT companies (INFORMANT 3).

It is also notable that there are links with companies of other industries. There is a patent development between the company studied and a mining firm: “This company (that shared the patent with the focal company) certainly did all the development [...] somehow participated of the process [...] made a technological cooperation that gave a benefit for both companies in their areas (mining and oil).”(INFORMANT 2).

They also license mature patented innovations to oil and gas service providers to project the Brazilian technology abroad. For that licensing, the service providers pay royalties for the focal company, generating additional revenues.

> SGN is licensed for at least three Brazilian firms [...] to project this technology abroad, they are operating outside Brazil [...] service providers in oil and gas...an oil company out of the country has a similar problem and it hires a company that provides clearance service [...] the institution being benefited pays only when it uses the technology (royalty) (INFORMANT 1).

Building strategic alliances, although essential to the development of product and service innovation, is not the main strategy for the development of process innovation in most cases (NIETO; SANTAMARÍA, 2010). In the studied lab, internal R&D developed approximately 80% of all patents. On the other hand, around 20% of the patents were developed by joint ventures with rivals or other types of strategic alliances. These empirical findings corroborate with the literature that stated that process innovation is mainly developed internally by the firms. The main goals of strategic alliances to develop process innovation are to share costs and risks.

Proposition 3 - A high level of process innovation performance achieved by an oil and gas firm might be more strongly related to a high level of investments in internal R&D than to innovative strategic alliances developed by the firm.

4.4 INCREMENTAL VS. RADICAL INNOVATION

The empirical evidence confirms that both incremental and radical innovation occurs. As shown in the following speech of an informant, new ideas that generate radical innovation usually emerge: “Sometimes you have an idea, you see a benefit for the company [...] if the staff of the operational area feels that your idea is a benefit, you fit it in the technological challenges of the company.” (INFORMANT 2).

However, incremental innovation is more common than radical innovation, as expected when you are developing process innovation. Next, an informant attests the importance of this type of innovation. “You have an innovation; a patent already exists, and you do a branch of it [...] if I develop it, I’ll solve another problem.” (INFORMANT 2).

First, the previously discussed focus on internal R&D is consistent with the development of incremental innovation as, for this type of innovation, an open innovation strategy is not mandatory (FORÉS; CAMISÓN, 2016). Besides, the analysis of the theory and of the empirical observations supports that process innovation occurs at a slower pace and more incrementally TERJESEN; PATEL, 2017) compared to product innovation. Two reasons probably influence that fact. First, product innovation deals with the development of a new product to the final customers and, if the firm is not fast enough, a rival may develop the product before and gain the customer. Therefore, the firm is usually forced to invest in radical innovations.

On the other hand, process innovation, as it occurs mainly internally, does not have the necessity to be developed in a hurry. The firm can catch a rival that increases its production by an earlier development of a radical innovation by copying or developing another innovation with similar results. Large-scale investments in the production process, which are commonly necessary for the oil and gas industry (OLIVEIRA, 2011), increase the risks of radical process innovation, encouraging a more incremental development. The discussion above leads to the following proposition.

Proposition 4 - A high level of process innovation performance achieved by an oil and gas firm might be more strongly related to a high level of incremental innovation than to a high level of radical innovation developed by its internal R&D.

4.5 APPROPRIABILITY REGIME

It is noteworthy the concern with the appropriation of the innovation's rents. The lab and the firm use several of types of appropriability mechanisms. As observed in the company's mission, vision and other documents analyzed, the firm studied adopts long-term strategies, as stated by the company's vision: "(Until 2030) […] being one of the five biggest and integrated energy companies of the world." (PETROBRAS, 2014, *online*).

We could apprehend from the interviewees that the firm also seeks to build barriers against rivals. The adoption of IPRs, tacit knowledge and HRM as appropriability mechanisms are consistent with the overall strategies adopted. These mechanisms are strongly adopted by the firm, according to the interviewees. This fact is positively related to innovation performance. Below, we have some evidence of the appropriability mechanisms used.

> All that can be verbalized is protocolled [...] you have a contract [...] sometimes involves more than two or three institutions [...] involves companies in the same industry, universities or research centers. (IPRs).
> Every company uses this way to protect (patent) [...] no other company can use my idea without paying royalties [...] it´s a global thing, common, much common [...] (IPRs).
> The guy has a chemical product and does not want to say what product is that [...] there are ways to publish a patent without giving so much information [...] some details that are essential to produce that product, you do not report…that is really common, every company does it. (Tacit knowledge).
> It's a way to hold this competence in the company [...] granting bonuses to some employees. This position of consultant to be able to stay with a comfortable salary to remain in the company [...] in the 90's we had a big evasion of professionals because the company was practicing a lower salary than the competitors. (HRM) (INFORMANT 3).

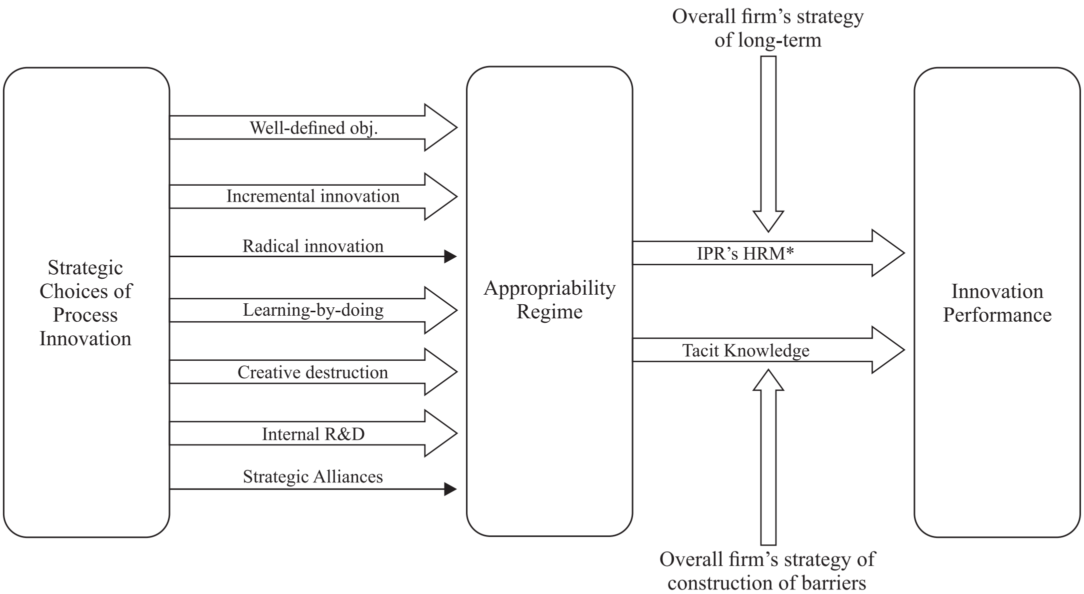
The technological complexity of the innovations introduced in the industry make some informal mechanisms efficient, such as HRM and tacit knowledge (ALNUAIMI; GEORGE, 2016; HALL; SENA, 2017). However, the licensing of technologies and weaker contracts characteristics of emerging countries like Brazil (CUERVO-CAZURRA; RUI, 2017) obligate the adoption of more formal mechanisms, such as IPRs, which are widely used in the oil and gas industry (CAVALHEIRO; JOIA; GONÇALVES, 2014). The strategy of creating barriers to rivals is commonly adopted by the industry, as well as long-term strategies. The case study empirically indicated the appropriability mechanisms that are used by the company and their rivals and that are appropriate for the strategies above mentioned. Therefore, the following proposition about the appropriability regime is derived:

Proposition 5 - Patents, tacit knowledge and human resources management (HRM) are efficient mechanisms to compose the appropriability regime to protect the process innovations developed by an oil and gas firm in order to enhance its process innovation performance.

Figure 1 summarizes the findings and the five propositions in a diagram. The thick arrows represent the intense or strategic use of strategies/appropriability mechanisms, and the thin arrows represent less intense or non-priority use. The left side of the diagram represents the strategies and choices to develop and implement process innovation, which are, primarily, well-defined objectives, incremental innovation, learning-by-doing, creative destruction and internal R&D. Secondary strategies, represented by the thin arrows, are radical innovation and strategic alliances, which are used in a minor proportion of the innovations developed. The right side of the diagram represents the appropriability mechanisms: IPRs and HRM, more associated with a long-term corporate strategy; and tacit knowledge, which is consistent with a corporate strategy of constructing barriers to rivals.

direct revenues. Although the firm has a strong hierarchical structure, the researchers operate as a matrix in some projects with the aim of achieving specific results.

The propositions, based on one case study and on literature review, do not allow to make generalizations. However, the study of a successful firm may bring lessons to managers from other organizations of the same industry in similar environments. As a general recommendation, we highlight that companies must invest in internal R&D to develop innovation as the main strategy when they intend



* IPRs - intellectual property regimes; HRM - human resources management
Figure 1 - Conceptual framework of process innovation development at the focal oil and gas firm
Source: elaborated by the authors.

5 FINAL CONSIDERATIONS

We could observe that the lab researchers apply innovative concepts intuitively according to most of the business academic's recommendations, although the team has not a formal knowledge of the theoretical concepts. The process innovations developed have multiple destinations. The main destiny is the internal adoption by the oil exploration and production units. Moreover, sometimes the innovations directly subsidize the company bottom line by licensing technology to competitors, generating

to develop process innovations. However, the opportunities of developing strategic alliances should not be neglected in some cases, both for a patent generation when the development incurs high costs and risks, and for licensing solutions to other companies. Considering firms that deal with huge investments, which seems to be the case of many oil and gas firms, an overall long-term strategy would be more appropriate. For that reason, the use of IPRs and HRM as appropriability mechanisms may be effective. The monetary investments needed for an efficient HRM are highly compensated by the lower turnover of skilled labor. This turnover could even help competitors to develop similar innovations by absorbing the knowledge of an employee that left the firm. To introduce barriers to competitors' misappropriation of owned innovation, tacit knowledge also may be an efficient appropriability mechanism.

In particular, we recommend to the top managers of oil and gas firms with similar sizes and that share the same challenges to consider the framework on Figure 1. Process innovation happens mainly incrementally, according to the evolution and new uses of current technologies. However, the firm should keep an eye open for the possibility of radical innovations to emerge from learning-by-doing situations. The strategic alignment must be focused on a well-defined plan and changes on it or emerging innovations should be discussed by the top managers to be approved and implemented.

The study intended to be exploratory and the development of the propositions is a contribution to the underexplored field of process innovation development in the oil and gas industry. It has some limitations regarding the unique case that does not allow analytical generalizations.

As a proposal for future studies, we recommend the use of more cases to validate and expand the model. More labs from the same company and similar labs from competitors may be analyzed to allow the proposition of a more accurate model for the industry. In addition, we could advance by conducting more triangulation to give more robustness to the research. Interview more people, from inside and outside the lab and the firm, as well as industry specialists, can lend more validity to the study. Other suggestion for future researches is the operationalization of the model on Figure 1 through the proposal of hypoteses and the collection of a representative sample to be statisticaly tested.

The goal of this study was to fill a gap in the literature of process innovation by investigating how process innovation is developed in a successful oil and gas firm. The R&D laboratory chosen as the case has an expressive number of patents, which is a recognized proxy for innovation performance. By developing a case-study analysis, this research contributed to the understanding of the strategic choices to conduct process innovation and the appropriability mechanisms to enhance the firm's innovative performance.

ESTUDO EMPÍRICO DA INOVAÇÃO DE PROCESSOS EM UM LABORATÓRIO DE P&D DE UMA FIRMA DE ÓLEO E GÁS

RESUMO

O principal objetivo deste artigo foi estudar como ocorre o desenvolvimento de inovação de processo em uma firma de óleo e gás de sucesso. Tentamos atingir esse objetivo por meio de uma análise de estudo de caso de um laboratório de P&D de uma multinacional brasileira de óleo e gás que é reconhecida por seu sucesso em inovar. Este estudo analisou o desenvolvimento da inovação ao investigar as escolhas estratégicas para desenvolver a renovação de processos e os mecanismos de apropriabilidade que permitem à firma se beneficiar das inovações. Concluindo, propusemos um modelo relacionando com as escolhas estratégicas e com os mecanismos de apropriabilidade da firma focal, que podem ser adequados para firmas de óleo e gás com estratégias genéricas similares.

Palavras-chave: Inovação de Processo. Apropriabilidade. Indústria de Óleo e Gás.

ESTUDIO EMPÍRICO DE LA INNOVACIÓN DE PROCESOS EN UN LABORATORIO DE P&D DE UNA EMPRESA DE ACEITE Y GAS

RESUMEN

El objetivo de este artículo fue estudiar como ocurre el desarrollo de innovación de proceso en una empresa de aceite y gas de suceso. Intentamos lograr tal objetivo a través de un análisis de estudio de caso de un laboratorio de P&D de una multinacional brasileña de aceite y gas que es reconocida por su suceso en innovar. Este estudio analizó el desarrollo de la innovación, al investigar las elecciones estratégicas para desarrollar la innovación de procesos y los mecanismos apropiados que permiten a la empresa se beneficiar de las innovaciones. Por fin, propusimos un modelo relacionado con las elecciones estratégicas y con los mecanismos apropiados de la empresa local, que pueden ser adecuados para empresas de aceite y gas con estrategias genéricas similares.

Palabras-clave: Innovación de Proceso. Apropiar. Industria de Aceite y Gas.

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