INNOVATION IN BRAZILIAN OIL INDUSTRY
From Learning by Using to
Prospective Capacity to Innovate in the Technological Frontier

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Diana Roa Rubiano²

Abstract

This paper analyses the process of innovation in the Brazilian Industry of Oil and Gas (BIOG). From the beginning, Petrobras, a state owned company, was at the command of the innovation process at the BIOG as a lead user, problem solver and risk taker. From learning by using, the company moved progressively the innovation ladder to the present situation at which it has developed the prospective capacity to take technological risks. This study compares the comfortable option of moving along the current technological trajectory and the alternative of intensifying the technological complexity of domestic suppliers for the BIOG. Our study identifies the fragility of knowledge bases among the Brazilian research community as a critical constraint for both trajectories. However, the new scale of the domestic oil and gas production offers a window of opportunities for radical innovations and improvement of the domestic knowledge base. To explore these opportunities, Petrobras must be able to use its the prospective capacity to innovate to induce the network of equipment and services suppliers (NSES) of the Brazilian industry of oil and gas (BIOG) to take larger innovative risks. We suggest that a larger knowledge base is crucial to see beyond the contemporary windows of opportunity and to reduce technological uncertainty.

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"A promising model for the understanding of scientific advances is one that combines the "logic" of scientific progress with a consideration of costs and rewards that flow from daily life and are linked to science through technology”

(Rosenberg, 1982, p. 159)

1. Introduction

The discovery of very large oil resources in the pre-salt prompted a drastic review in the Brazilian oil policy. A new institutional arrangement was adopted for the exploration of these resources (De Oliveira, Forthcoming) and the policy for local content of goods and services gained momentum. Petrobras investments escalated rapidly\(^3\) to reach US$ 157 between 2011-2014, but the company perceived that it could hardly achieve the local content commanded by its exploration licenses.\(^4\) The bulk of its domestic supply of equipment and services is not competitive and the lack of technological capabilities of the domestic manufacturing industry is at the core of this problem (De Oliveira, 2008).

In the 1970’s, Petrobras adopted the Floating Production System and Offloading (FPSO) for the exploration of oil reserves at Campos basin. This technological trajectory proved successful, allowing the company to become a leading operator in the offshore. The pre-salt resources open a window of opportunities for radical innovations that could move the offshore oil exploration to a new technological trajectory. This is a riskier strategy but it offer likelihood of much larger benefits in the long run. Petrobras can hardly look for this new trajectory without the cooperation of its network of suppliers of equipments and services (NSES). For a successful transition to a new technological trajectory, the company needs to persuade its suppliers to take larger technological risks. This paper looks at the potential difficulties to do so.

After this introduction, the paper is organized in two sections and a conclusion. The next section reviews the three periods of technological learning that the Brazilian industry of oil and natural gas (BIOG) went through so far. It aims to identify the economic forces that have been pushing Petrobras technological policy so far and to

\(^3\) Petrobras announced investments for U.S. $ 157 billion for projects until 2014 and an additional US$ 290 billion post-2014. The investments are part of the Company's Business Plan, which is in development phase and involves 645 projects (See Appendix Table 6).  

\(^4\) Brazilian regulation demands that the company reach a minimum level of domestic acquisition of equipments and services.
explain the Petrobras role as a leading user, problem solver and risk manager of the BIOG.  

Section three examines the strategies used by Petrobras to move its suppliers` innovation policies, using the concept of technology as knowledge and technological development as a process of problem solving (Carlsson, 1995). Section four compares the comfortable option of moving along the current technological trajectory and the alternative of intensifying the technological complexity of domestic suppliers. The first option concentrates its strategy in incremental innovations and the customization of domestic suppliers for the supply of the oil industry. The alternative trajectory searches to introduce an array of radical innovation that would offer an international competitive edge for the Brazilian NSES. Risk management is the key dividing issue between these two strategies.

2. The BIOG Innovation Process in Retrospect

So far, the BIOG history is a product of defensive institutional strategies to cope with the forces of international oil market and of active strategies to find domestic oil resources that would remove the oil vulnerability of the Brazilian economy. This history gained momentum after the creation of Petrobras, a state owned monopolistic company in 1954. Two central features marked this history: (i) the behaviour of the international oil market (price swings), and, (ii) findings of oil resources (domestic endowment).

From its inception, PETROBRAS exerted a significant influence on the development of NSES. However, the dynamics of technological learning of Petrobras has not been followed by its domestic suppliers. The company technological strategy has been strongly influenced by the oil price (fixed internationally) while the NSES technological strategy was determined by the conditions of the domestic industrial policy.

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5 This is an interesting example of how a company can be beneficiary and architect of public policies for industrial development at the same time.

6 The struggle for oil supply in Brazil begun in the 1930s as a product of a nationalist concern with security of oil supply (Cohn, 1968)
Demand Pull

At the beginning of the 1950’s, the fast growing of imports of oil derivatives was perceived as a major constraint for the economic development of Brazil. Petrobras was set up with the target of removing this constraint. To achieve this objective, the company received autonomy from government to use scarce foreign currencies to provide competitive, secure supply of oil derivatives to support the country industrialization (De Oliveira, Forthcoming). In a period of low, declining oil price (Figure 1), the probability of finding domestic oil reserves onshore was low. Petrobras concentrated its technological strategy in the downstream operations of the oil industry.

The 1970’s oil shocks and the discovery of offshore oil resources in the Campos basin induced Petrobras to move its technological strategy to the exploration of oil in the offshore. The pressure of oil imports remained a major constraint for the Brazilian economic growth and government invited international oil companies to share the risks of oil exploration with Petrobras (De Oliveira, 2008). Unease with the economic regulation offered by the Brazilian government, the international oil companies walked away from the Brazilian continental shelf when the oil price dropped from its peak in the 1980’s. Lower oil prices suggested lower profits. International oil companies became more risk averse and they reduced their investments, including R&D investments (Creusen & Minne, 2000).
Petrobras moved the other way round. Pressed but at the same time supported by the government policy of oil self-sufficiency, the company decided to take higher risks investing in deeper waters. A set of giant oil fields was found and to develop these fields, Petrobras decided to break away from the follower technological strategy that the company had adopted so far. The acquisition of proven foreign technologies was replaced by the development of technologies for the Brazilian deep offshore in close cooperation with Petrobras international suppliers of equipment and services. This technological strategy proved rewarding: Petrobras offshore oil production jumped from 1.969 b/d in 1981 to 18.048 b/d in 2009 (Figure 2) and the pre-salt oil resources are estimated in the range of 50 to 90 billion barrels of hydrocarbons (oil plus natural gas).

![Figure 2](image)

Nowadays, oil imports are no longer a major constraint for the Brazilian economy.7 However, the pressure to increase the domestic oil production should remain. The pre-salt oil production is essential to diminish the OECD countries dependence of oil imports from politically difficult regions. For Brazil, the pre-salt discoveries in a period of higher oil price mark a transformation of the BIOG. To develop these resources large investments have to be made offering a fertile ground to begin a new period of technological learning and for the introduction of radical innovation. Properly conducted, this period can generate an internationally competitive Brazilian NSES.

7 Actually Brazil became a net exporter of crude oil recently.
**Technological Push**

Once reserves are found, the oil price and their production costs drive the strategy of the oil companies. Prices are determined at the market place but costs are largely established within the knowledge base and the innovation capabilities commanded by the oil company. Petrobras recognized these facts from its very beginning. Unable to control the oil price, the company was organized to minimize costs, developing its knowledge base and governing the innovation process of the BIOG. For the acquisition of technological capabilities, Petrobras created a research centre (CENPES) and to develop the domestic supply of its needs of equipments and materials a technical division (SERMAT) was created as well.

The company initial efforts were concentrated to the learning of mature downstream technologies. By the end of the 1970’s, Petrobras had acquired extensive technological capabilities for its downstream operations, a large share of the company demand of equipments and materials was domestically produced\(^8\) and Brazilian universities were offering education programs related to oil activities as well.

A new period of technological learning started after the discovery of offshore oil reservoirs in the 1970’s. Petrobras used Early Production Systems (EPS) to develop these reservoirs, a concept adopted by international oil companies for the oil fields in the North Sea. Gradually the company moved through the offshore exploration learning curve, from shallow to deep water, first assimilating standard technologies and later developing the concept of floating production storage and offloading (FPSO), largely and successfully used by Petrobras nowadays.

In the middle of the 1980’s, the discovery of giant oil fields in deep waters in a period of oil price decline created a new technological context for Petrobras. Short of oil to feed its refineries, the company was willing to develop the new discoveries but new technologies, not available among its suppliers of equipments and services were needed. Petrobras decided to move forward from its imitative, assimilative technological traditional conduct, to take technological risks in the deep offshore (Toribio Dantas, 1999). The company launched a research program (PROCAP 1000) with the purpose of developing pioneer innovations for oil exploration in deep waters (1000m).

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\(^8\) It is important to remark that domestic suppliers had substantial protection against imports.
Seven (7) specific projects were developed (Table 1) aiming to develop new concepts and products for the exploration of oil in the Brazilian offshore. These projects generated significant gains of knowledge to improve the oil production processes. The search for innovation became a coordinated effort of its research centre (CENPES), its engineering department (SEGEN) and its materials and equipment procurement service (SERMAT). Since then, Petrobras launched two new PROCAPs to produce at increasingly deep waters (2000m and 3000m).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sample Projects PROCAP 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Knowledge Bases Development (State of Implementation)</td>
</tr>
<tr>
<td></td>
<td>Notion – conception</td>
</tr>
<tr>
<td>Subsea Pumping</td>
<td>X</td>
</tr>
<tr>
<td>Tension Leg Platform –TLP-</td>
<td>X</td>
</tr>
<tr>
<td>X-mas Tree</td>
<td>X</td>
</tr>
<tr>
<td>Manifold –driverless-</td>
<td>X</td>
</tr>
<tr>
<td>Manifold (Octos 1000)</td>
<td>X</td>
</tr>
<tr>
<td>Semi submersible Platform (Vitória-Régia)</td>
<td>X</td>
</tr>
<tr>
<td>Remotely operated vehicle products</td>
<td>X</td>
</tr>
</tbody>
</table>

TT* Transference of Technology from foreign firms
Source: (Tosi Furtado & Gomes Freitas, 2004)

Differently from the first, these PROCAPs searched to improve the knowledge base in close cooperation with both domestic and international companies and research centres. As a result of this strategy Petrobras patents relating to oil exploration tripled in the 2000’s (Figure 3).

The pre-salt discovery marks the beginning of a new innovation strategy at Petrobras. The set of technological challenges that have to be addressed to fully develop this new oil province is great. To face these challenges, Petrobras increased spectacularly its R&D investments (Figure 4), created arrays of technological innovation with Brazilian and foreign universities, and attracted several research centres of its multinational suppliers of equipments and services to the surrounding area of CENPES. While the previous PROCAPs were largely looking for incremental innovation along the technological trajectory initiated in the 1970’s, Petrobras is this time searching for

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9 The reservoirs are at 300 Km from the coast, an extensive layer of salt has to be drilled before arriving to the oil layer, new alloys are needed to guarantee the integrity of the wells, processing of large amounts of CO₂, mooring at 2200m water depth, etc.
radical innovations that could shift the deep offshore exploration to a new technological trajectory eventually.

**Figure 3**
Count of 1969-2010 Utility Patents Grants* and E&P Investments

*By Calendar Year of Grant

Sources: Based on data from ANP (Agência Nacional de Petróleo) for investments and USPTO for patents

**Figure 4**
Petrobras Investments in R&D

Source: Petrobras

In the past, the Petrobras technological search for the offshore was driven by the perception of needs identified at the oil production platforms. This approach is no longer effective to address the technological complexities of the pre-salt. In this case, to reduce the technological uncertainties to acceptable levels, it is necessary to sharpen the ability to find technological guidance *ex ante* in the foundations of scientific knowledge.
In other words, the technological push should have a larger influence in the innovation process of the pre-salt.\textsuperscript{10}

One of the world leaders in deep offshore, PETROBRAS has a dominant position in the BIOG and has a small, but growing presence abroad as well (De Oliveira, Forthcoming). Its know-how and its capacity for risk taking turned the company into a leading offshore technological developer. These credentials suggest that Petrobras can go a step further in the offshore innovation process, coordinating its know-why searching.

3. Petrobras Innovation Policy for the NSES

In conceptual terms, technological systems are defined as a network of agents involved in the generation, diffusion and utilization of technology, interacting under a particular institutional arrangement, for the supply of equipments and services for a specific industry (Carlsson, 1995). The BIOG has Petrobras at the top of its technological system and a vast array of firms (NSES) that supply the company with its needs of equipments and services. Given its strategic role in the BIOG, the company intends to use its innovation policy and its purchasing power to induce innovative behaviour among the NSES.

\textit{Coordinating Innovation in the BIOG}

Innovation is a complex process moved by both knowledge creation and market forces that contains a large degree of uncertainty (Mikkelsen, Jøsendal, & Steineke, 2003). In theory, firms are less averse to allocate resources in innovation if: (i) they know or believe the existence of some kind of scientific and technological opportunity unexplored, (ii) they expect that there is a market for their new products or new processes, and (iii) they expect a net profit of the innovations expenditures (Dosi, 1988). Usually, the innovation history starts with specific needs (Carlsson & Jacobson, 1995) and when piloted by a leading user is more likely to have commercial success (Von Hippel, 1975). Petrobras embraced the role of leading user and pilot of the innovation process in the BIOG value chain.

\textsuperscript{10}Lundvall y Johnson (1994) studied the components of knowledge, distinguishing among technological information (know what), scientific principles( know why), and practical specific abilities (know how).
Until the 1980’s, Petrobras operated its innovation policy under the protective umbrella of the import substitution policies of the Brazilian government.\footnote{11} The company provided generous incentives for its domestic suppliers of equipment and services\footnote{12} while the national development bank (BNDES) provided soft funding for the development of supply capacity among BIOG suppliers. This institutional arrangement is largely accountable for the current domestic capacity to supply capital goods to the Brazilian economy nowadays.

In the 1980s, the Brazilian economy got into a long period of stagnation and crisis. Successive economic stabilization shocks provoked induced domestic industrial suppliers to innovative inertia.\footnote{13} Petrobras was in different atmosphere. Pressed by the government need to reduce oil imports, the company had strong incentives to develop the offshore reserves identified in the Campos basin, despite the lack of accurate quantification of returns on its investments. Its monopoly position and soft budget constraint allowed the company to be more aggressive at investing in technology-intensive offshore exploration and development than it would have been if the government was not implicitly underwriting these efforts (Nolan & Thurber, 2010).

With no domestic support for innovation, Petrobras had no alternative but to look internationally for its supply of the innovative equipment and services needed to produce oil in the Campos basin. The Petrobras ability to coordinate the domestic supply of its needs of equipments and services dwindled and the NSES lost many opportunities to enlarge its supply. Petrobras approach to innovation became less averse to risk however. Moreover, the company developed an acute capacity to identify innovation opportunities as well.

It is usually assumed that successfully risk taker companies induce other firms to take risks as well (Carlsson & Jacobson, 1995). However, the NSES could hardly take innovation risks within the Brazilian economic context of the 1980’s and the 1990´s. These opposing trends explain the reduced participation of domestic firms and Brazilian universities in the thirteen (13) strategic innovation projects conducted by Petrobras between 1980 and 2006. Although these projects involved more than 100 firms,

\footnote{11} Whenever there was domestic supply alternative, imports were strongly penalized with tariffs.
\footnote{12} Petrobras used its purchasing power to facilitate the transfer of technology and the company offered contracts to domestic suppliers as well.
\footnote{13} By the end of the 1980’s, the Brazilian industrial sector was “well behind in terms of technology and product processing, and particularly, the organization of production” (Kupfer, 2003, p. 7)
research institutions and universities, only five (5) Brazilian Universities and four (4) domestic firms were active in the Petrobras innovation process. As a result of this situation, “the external knowledge sources that were drawn into these new forms of knowledge network began to include almost only suppliers and foreign agencies” (Dantas & Bell, 2009, p. 836).

In the 1990's, the Brazilian government abandoned the import substitution policies and the oil monopoly of Petrobras was removed. Facing competition, the company made a radical change in its relationship with the NSES. Petrobras started to use EPC (engineering, procurement and construction) companies for the supply of its needs of equipment and services. Differently from Petrobras, the EPC companies have no culture of fostering the NSES. Their single objective is to minimize costs, searching for the lower supply prices available either domestically or internationally. Placed in a new innovative, internationally competitive context, the NSES responded adopting defensive innovation strategies based on the assimilation of external knowledge embodied in machinery, in spite of the sustained growth of the domestic oil production. However, the deep offshore requires suppliers able to innovate based on scientific knowledge. Eventually, Petrobras diminished the ability to coordinate its domestic supply or equipments and services while the NSES reduced the ability to supply the technological needs of the BIOG. Inevitably, the domestic content of Petrobras projects decreased.

Realizing that the NSES was not prepared to supply competitively the BIOG, government introduced a clause for domestic content in the licensing process for oil exploration and created a program that intends to increase its domestic supply of equipments and services (PROMINP) as well. These government policy tools managed to increase the supply of the NSES but its competitiveness remain a critical weakness, largely as result of the poor innovative efforts of the NSES as yet (De Oliveira, 2008). Nevertheless, government intends to substantially increase the share of NSES in the BIOG.

\[A \text{ new regulatory environment was created in which Petrobras have to compete with other oil companies for the licensing to explore oil blocks (De Oliveira, Forthcoming).}
\[\text{The import ratio of manufacturing Brazilian industry went up from 4.3 in 1990 to 14.8 in 2001 (Ribeiro \\
\& Pourchet, 2002).}
\[\text{Oil companies assume a contractual agreement to achieve a minimum level of domestic content in their activities to explore the licensed oil block. For more details, see www.anp.gov.br.}
\[\text{PROMINP is coordinated by Petrobras. For more details see www.prominp.gov.br}

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To enforce that policy, government created a new state owned company that should command the purchasing power of the pre-salt oil fields.\textsuperscript{18} Moreover, a new regulatory framework was introduced for the exploration of pre-salt resources which requires that Petrobras must be the single operator of pre-salt oil fields. Government intends to use the purchasing power of PETROBRAS and the domestic content of the licensing process to enhance the NSES economic competitiveness. However, it is important to remark that the ability of the NSES to move its innovation effort towards to the technological frontier off the deep offshore is largely dependent of the coordination of the EPC companies.

**Dimensions of Petrobras Innovation Policy**

We can situate the Petrobras supply of equipments and services in a space with two dimensions: the degree of customization\textsuperscript{19} and the technological maturity of the supply, distinguishing four (4) quadrants in this space (Figure 5).

\textsuperscript{18} The Pre-Sal Petroleum Company was created but not organized as yet.

\textsuperscript{19} Meaning the share of the firm output offered to the BIOG.
• **Quadrant I: equipments and services based on mature technologies that are largely used in other sectors of the economy.** Their competitiveness is driven largely by scale and they compete in terms of price, although delivery time and the quality of their products are relevant for their competitiveness as well. The bulk of the NSES firms are supplying this group products and Petrobras has little leverage to push technological change among them.

• **Quadrant II: equipments and services based on mature technologies that are largely used in the oil industry.** Their competitiveness is driven by their ability to satisfy the technological specifications of the BIOG. In this case, the observation of delivery time and the obedience of quality specifications demanded by the Petrobras are more relevant than scale for their competitiveness. The company has leverage to induce innovation among these firms but has to provide mechanisms to mitigate their risk aversion, especially in terms of scale to supply the domestic market.

• **Quadrant III: equipments and services based on radical innovation that are largely used in the oil industry.** Innovation is driven by opportunities at the technological frontier of the oil industry worldwide. Petrobras plays a critical role in the identification of those opportunities and the company has substantial leverage to induce innovation. However, Petrobras is required to share the innovation risks with its suppliers.

• **Quadrant IV: equipments and services based on radical innovations that are largely used in other sectors of the economy.** Although Petrobras can identify opportunities for innovations that are relevant for its technological performance, the company ability to induce innovation among this group of firms is limited. Innovations of this quadrant are not necessary designed to the oil industry. They have a wide-range use and they are flexible to be adapted to other industries than oil.\(^20\) For example, suppliers of special materials are able to provide products and services for aerospace, mining, paper, waste, cement, mineral processing and food processing.\(^21\) To improve its ability to induce

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\(^{20}\) Most of the empirical studies of patterns of diversification refer to the notion of “technological proximity” in explaining diversification in output (Pavitt, 1984)

\(^{21}\) The FMC Company is the major supplier of subsea equipment for the PETROBRAS. In the BIOG, that firm has an important (exclusive) participation in the market, with an appearance dependence of this
innovation in the group of firms, Petrobras has to coordinate its innovation policy with other sectors of the economy, accepting that scale is essential to move forward the innovation process.

Petrobras uses horizontal and vertical innovation strategies to move its suppliers among these four (4) quadrants (Figure 6). The horizontal strategy intends to increase the share of the firm supply oriented to the BIOG, adding new products to their supply line, more often with incremental technological change. The vertical strategy searches to induce radical innovations that are often at the BIOG technological frontier and can eventually lead to new suppliers.

Figure 6
Dimensions of Petrobras Innovation Policy: Tools and Arrangements

For the horizontal strategy, Petrobras adopted the concept of Technical Cooperation Agreements (TCA) managed by the Materials Engineering Management (EMAT). The company offers support from its engineering department for suppliers interested to produce equipments not available in the domestic market (Alonso, Rovina, & Martins, 2007). Petrobras signed more than 100 TCAs with domestic manufacturers and research institutes already (Table 2). In these contracts, the knowledge flows both ways.
Petrobras gets practical learning about equipment performance and operational activities while the domestic manufacturers adopt new concepts and develop new products and technological capabilities.\(^{22}\)

\[\text{Table 2} \]
\text{TCAs results (1998-2006)}

<table>
<thead>
<tr>
<th>Cooperation Agreements with firms</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agreements executed in partnership with universities</td>
<td>40</td>
</tr>
<tr>
<td>Cooperation Agreements in final negotiation phase:</td>
<td>30</td>
</tr>
<tr>
<td>Technical Support Homologation, without requiring a TCA:</td>
<td>150</td>
</tr>
</tbody>
</table>

Source: (Alonso, Rovina, & Martins, 2007)

The vertical strategy is mainly oriented to radical innovations. Petrobras establishes collaborative research arrangements with competitors to develop the technological frontier of the oil industry.\(^{23}\) In these cases, CENPES is put at the top of the innovation process and the company accepts to take a large share of the market risks of the suppliers. To improve its ability to promote radical innovations, Petrobras recently tripled the research capacity of CENPES and attracted several research centres strategic suppliers to the vicinity of CENPES (Table 3).

\[\text{Table 3} \]
\text{Scientific and Technological International Centers installed in Brazil}

<table>
<thead>
<tr>
<th>Scientific and Technological Centers installed in Brazil</th>
<th>SME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker Hughes</td>
<td>ESSS - Engineering Simulation and Scientific Software</td>
</tr>
<tr>
<td>FMC Technologies for Brazil Ltda.</td>
<td>ILOS - Logistic and Supply Chain.</td>
</tr>
<tr>
<td>Halliburton</td>
<td>Lab Ocean</td>
</tr>
<tr>
<td>Schlumberger</td>
<td>LAMCE – LABCOG</td>
</tr>
<tr>
<td>Usiminas</td>
<td>LEAD</td>
</tr>
<tr>
<td>Tenaris Confab</td>
<td>NEO – Nucleus of Oceanic Structures – COPPE/UFRJ</td>
</tr>
<tr>
<td></td>
<td>NUTRE</td>
</tr>
<tr>
<td></td>
<td>PAM Membranes</td>
</tr>
<tr>
<td></td>
<td>RECAS</td>
</tr>
</tbody>
</table>

Source: COPPE – Federal University of Rio de Janeiro

The company vertical strategy for innovation induces scientific cooperation between Petrobras and its suppliers that promotes the knowledge base creation for the BIOD. Indeed, perceiving the increasingly role of knowledge assets outside its boundaries, Petrobras created networks of research centres for the search of fifty (50) strategic

\(^{22}\) The TCAs cover a wide variety of technologies, like for instances: subsea valves, submersible centrifugal pumping, new flexible lines, shared action manifolds, wet christmas tree for 2500m. (Alonso, Rovina, & Martins, 2007)

\(^{23}\) The collaboration the Kvaerner, a Norwegian company, for the development of a Petrobras-designed wet Christmas tree is a good example of this innovation strategy (Dantas & Bell, 2009)
technologies. These networks involve both domestic and international research centres and universities. As result of this policy, Petrobras is gaining growing importance as a source of frontier technological knowledge in the oil industry (Dantas & Bell, 2009, p. 837)

Aware of its limited leverage to induce innovation in the first and fourth quadrants, Petrobras concentrated its innovation policy among firms situated in the second and third quadrants, mostly among multinationals that supply key products and services for the company operations. So far, Petrobras has not tried to develop competitive advantages that would allow the NSES as a whole to forge ahead through the technological frontier of oil industry. The NSES innovation policy has been oriented to the assimilation of knowledge via learning by using the expertise embedded in machinery and equipment. This innovation strategy puts Petrobras in a situation of technological dependence of imports of technologically innovative products from suppliers that are not strategically linked to the company. More important, it does not satisfy government local content policy. In the long run, this strategy jeopardises Petrobras leading position in the deep offshore.

4. Opportunities, Risks and Uncertainties

Resource allocation between the exploitation of existing technologies and the exploration of new technological trajectories embodies temporal, institutional and economic preferences. The exploration of a new technological trajectory involves risks and it reduces the speed at which existing skills are improved (March, 1991, p. 72). This is a relevant aspect to be considered, especially if the lift of the oil reserves is the main objective pursued. However, if the development of an internationally competitive NSES and the protection of the environment are the main policy goals, a new technological innovation trajectory must be considered.

**Pre-Salt Technological Trajectories**

To develop the pre-salt reserves, there are three possible trajectories (Da Silva, 2011):

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24 Government created the Program for the Mobilization of the Suppliers of the BIOG (PROMINP) to increase the domestic supply of equipments and services to the BIOG.

25 This choice was presented to the UK and Norway in the 1970’s, after the discovery of the North Sea oil reserves. Norway choose to develop the domestic network of suppliers while the UK preferred to speed up the oil production (Hatakenaka, et.al., 2006)

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1. Continuity: Petrobras improves the technological system adopted in the Campos basin (FPSO and wet completion) so far;
2. Intermediary: Petrobras implements Tension Leg Platform and SPAR Platform with topside subsea solution;
3. Path breaking: “subsea to beach” technologies.

The continuity trajectory searches for refinement of solutions that were implemented by Petrobras already (table 4). In this case, Petrobras take advantage of the extensive technological learning in the Campos basin to adapt existing technologies to the challenges of the BIOG. This option has low technological uncertainty and measurable cost of experimentation. Nevertheless, it will not put Petrobras at leading edge of the oil industry.

Table 4
Topside solutions in projects in O&G Industry

<table>
<thead>
<tr>
<th>Topside solutions in projects operated by Petrobras in Brazilian fields</th>
<th>Similar projects in the International Subsea Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barracuda and Caratinga</strong> – development project involved the construction, start-up, ownership and operation of deep-sea production facilities located in the central part of the Campos Basin. (FPSO Technology)</td>
<td><strong>45 PROJECTS</strong>&lt;br&gt; (18) AFRICA&lt;br&gt; (16) North Sea, (4) AUSTRALIA&lt;br&gt; (2) CANADA&lt;br&gt; (2) CHINA&lt;br&gt; (2) INDONESIA&lt;br&gt; (1) NEW ZEALAND</td>
</tr>
<tr>
<td><strong>Espadarte</strong> - is located approximately 110 km from the coast of Brazil in the Campos Basin in a water depth range of 750 to 1,500 meters. (FPSO Technology)</td>
<td><strong>10 PROJECTS</strong>&lt;br&gt; All in the Gulf of Mexico, USA</td>
</tr>
<tr>
<td><strong>Roncador</strong> - This semisubmersible had been producing 84,000b/d and 1.3 million m³/d of gas. (FPSO Technology)</td>
<td></td>
</tr>
<tr>
<td><strong>Marlim Sul</strong> located 110km off the shore Water depth varies from 720m in the north, to 2,600m in the south of the field. (FPSO Technology)</td>
<td></td>
</tr>
<tr>
<td><strong>PROCAP 2000</strong> - To produce oil and gas from offshore fields situated in ultra deep waters (of 1,000-3,000m), with the aim of incorporating the reserves located at these water depths. (SPAR Technology)</td>
<td><strong>12 PROJECTS</strong>&lt;br&gt; (8) Gulf of Mexico, USA&lt;br&gt; (2) North Sea, Norway&lt;br&gt; (2) Barents Sea, RUSSIA</td>
</tr>
</tbody>
</table>

Table 4
Topside solutions in projects in O&G Industry

Source: [www.subsea.org](http://www.subsea.org)
The intermediary trajectory intends to assimilate concepts that are used elsewhere. It will move Petrobras to a new period of learning by using that involves relatively low technological risks. This technological trajectory can pair off Petrobras to the leading multinational oil companies eventually. However, Petrobras will remain largely an innovation follower that adapts technologies developed by its competitors to the Brazilian offshore specificities. It is important to remark that both the continuity and the intermediary strategies have the critical environmental challenge to surmount as yet. Indeed, the accident at the deep horizon platform in the Mexican Gulf suggests that radical innovations are needed to avoid new accidents like that.  

The path breaking trajectory demands radically new concepts for the deep offshore exploration. This choice envelops large uncertainties but the rewards are likely to be higher both in terms of environmental safety and diminished costs as well. If successful, it will give a leading international position for both Petrobras and the NSES. In this case, the technological challenges are numerous and several connections among different scientific knowledge bases need to be made, as pointed out at the fourth National Conference on Science, Technology and Innovation (J. Braz. Chem. Soc., 2010).

Generally the analysis of the innovative capacity of firms is based on the evaluation of products and processes that result from their innovative efforts (ex-post evaluation). Another way to look at innovative capacity of firms is to evaluate their ability to predict and to take advantage of the window of opportunities that can move the industry to new technological pathways (ex-ante evaluation). Our review of Petrobras innovation policies suggests that the company is prepared to use its large flow of investments to pull a prospective (ex-ante) innovation strategy among its suppliers and their interaction with the technological system for the lift of the pre-salt oil reserves. However, the development of the domestic knowledge base among the NSES firms is essential to

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26 There are around 60 companies looking for different environmental solutions for the deep offshore (environmental hydraulic fluids - environment monitoring - oil spill - oil treatment - water treatment - pollution control and prevention - pollution control - safety control - waste handling - well control services).

27 This assumption is accordance with the concept of technological systems defined in terms of knowledge/competence flows rather than flows of ordinary goods and services.

28 Considering technological system as a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology (Carlsson, 1995)
move the BIOG beyond the oil industry technological frontier. Table 5 presents the knowledge bases, the Brazilian academic production related to the oil industry and the number of firms that offer equipments and services to the oil industry worldwide.

Table 5

<table>
<thead>
<tr>
<th>Key activity</th>
<th>Knowledge base</th>
<th>Number of Subsea Companies</th>
<th>% of Total Subsea Companies</th>
<th>Brazilian s Postgraduate Theses</th>
<th>% Theses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>Collecting geological data</td>
<td>Navigation, Seismology, Engineering/material technology</td>
<td>899</td>
<td>10,31%</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Analyzing geological data</td>
<td>Geology, Geophysics, Geochemistry</td>
<td>56</td>
<td>0,64%</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seismology</td>
<td>66</td>
<td>0,76%</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Engineering and manufacturin g the installations</td>
<td>Industrial instrumentation, design/material technology, engineering/physics, geology, mechanics, machinery</td>
<td>1289</td>
<td>14,79%</td>
<td>1272</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Build/material technology, geometry, subsea technology construction, optimization</td>
<td>137</td>
<td>1,57%</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td>Mechanical engineering, electronics, subsea technology machine</td>
<td>186</td>
<td>2,13%</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cibernetics, Geometry</td>
<td>136</td>
<td>1,56%</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>Engineering/ material technology, geometry, subsea technology, optimization, mechanic engineering, electronics, subsea technology machine maintenance, cibernetics</td>
<td>85</td>
<td>0,97%</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Surveillance</td>
<td>IT -engineering, computer imaging, electronics, MR, optics, acoustics, wave analysis, climatology</td>
<td>50</td>
<td>0,57%</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Well handling, reservoir technology and transportation</td>
<td>Geology, geophysics, geochemistry, geological engineering, numerical simulation, engineering/material technology, geochemistry</td>
<td>3199</td>
<td>36,69%</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Safety and Environment</td>
<td>Varieties</td>
<td>98</td>
<td>1,12%</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Well handling, reservoir technology and transportation</td>
<td>Geochemistry</td>
<td>68</td>
<td>0,78%</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Distributing and selling refined products</td>
<td>Varieties</td>
<td>2449</td>
<td>28,09%</td>
<td>378</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>8718</td>
<td>100%</td>
<td>2606</td>
</tr>
</tbody>
</table>

Source: Base on (Smith, 2000) and (Braadland, 1997)
Data from Capes and subsea.org

29 The concept of knowledge base is related to scientific institutions focused on the production, organization and dissemination of knowledge (OECD, 1990).
30 The oil industry is related to more than 30 knowledge bases, including oceanography, climatology, cybernetics, biotechnology, acoustics, physics, geophysics, chemistry, geochemistry, etc. (Smith, 2000).
The key point is the wide array of knowledge inputs across many activities, and the very substantial number of specialised suppliers. It can be seen that the Brazilian effort to develop the knowledge bases relevant to BIOG is relatively poor as yet, and not evenly distributed. Although we have no organized data, scattered information suggests about the scientific and technological infrastructure involved in generating, supplying or maintaining the domestic knowledge bases for the oil industry is weak. Indeed, the academic production (theses and dissertations) is concentrated in the development of wells and research on safety and environmental protection, critical aspects for the deep offshore, is very limited.

To push innovation forward among NSES firms, a domestic critical mass of research capabilities able to operate in a context of technological complexity, uncertainties and deep knowledge of scientific knowledge bases has to be developed. In 1999, the Ministry of Science and Technology created a program (CTPetro) to stimulate innovation among the NSES that provide funding for cooperative research activities between universities and firms. After that, the number of post graduate academic degrees related to the oil industry that are released every year by Brazilian universities increased rapidly. Nevertheless, it is important to remark that this movement has not produced a noticeable improvement in the innovative effort of the domestic NSES. Indeed, cooperation between universities and NSES firms is very limited as yet. This interaction needs to be intensified in terms of both human capital and technological information flows (de Oliveira, 2008). It is worth to remark that the number of firms controlled by Brazilian nationals is only eight (8) in the universe of 8718 suppliers of the subsea industry indicated in table 5.


**Figure 7**  
Theses and dissertations related to Oil and Gas in Brazilian Universities (1987-2009)

Source: Based on Capes and ANP data

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**Innovation Risk Management**

A recent study of the competitiveness of a set of suppliers of the NSES identified several shortcomings in both Petrobras and government policies that difficult the NSES innovative performance (De Oliveira, 2008). Petrobras uses idiosyncratic technological approaches to satisfy the supply its operational units disregarding technological standards used internationally. Moreover, there is no coordination of purchases among the units of the company, a situation that creates demand peaks and valleys that suppliers can hardly accommodate in their business plans. These policies block the exploration of economies of scale among NSES firms, a fundamental piece of their competitiveness.

Government introduced a local content obligation for the licensing of oil blocks intending to support the NSES competitiveness but paid no attention to the innovation policy needed to increase the NSES ability to supply the Petrobras technological needs. Indeed, the NSES firms indicate that the country has not enough engineers and even
technicians to activate their innovative efforts. Furthermore, the financial incentives offered by government for innovation are oriented to university research centers but there are no incentives for links between universities research activities and firms in need of technological change.

After decades of effort to dominate mature technologies, the NSES firms face the challenge of breaking through technological boundaries to take advantage of the technological opportunities offered by the pre-salt but their innovation efforts remain focused on the acquisition of new machines. Few NSES firms develop innovation efforts and they are exclusively oriented to the adaptation of products to the idiosyncratic demands of Petrobras. Although the opportunities for radical innovations offered by the pre-salt are very attractive, the uncertainties involved to break through technological boundaries are very high.

Uncertainty is more than the lack of relevant information about events. It is also the existence of unresolved problems that we are unable to predict the consequences of action (Dosi, 1988, p. 222). The undergoing effort to develop the domestic knowledge bases will reduce the pre-salt uncertainties eventually. However this effort has to be articulated with innovation at the firms’ level in such way that they can be able to evaluate their innovation risks (OECD, 1990, p.p. 24). The understanding of risks enables firms to transform their attitude towards innovation. The capacity to manage risk increases their appetite to make forward-looking choices. Risk management is the key element that drives the economic system forward. The mitigation of the pre-salt innovation risks is vital to move up them up throughout the technological ladder.

It is estimated that the NSES will have to invest US$ 400 billion in the coming years to supply the local content of the BIOG. These investments offer many opportunities for innovation but there are risks and uncertainties in all three trajectories (continuity, intermediate and path breaking) envisaged. The perception of risks and the aversion to take risks will be determinant in the NSES firms decision to invest.

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31 Skills and knowledge are both inputs and outputs of innovation that often require training to improve innovation (OECD, 2011).
32 The revolutionary idea that defines the boundary between modern times and the past is the mastery of risk. (Berstein, 1998).
Firms operating in the first quadrant of Petrobras innovation strategy face the risk of technological obsolescence (figure 8). This risk is related to the vulnerability of mature technologies to emerging technologies related to pre-salt technological demands. The timing for innovation for these firms is largely determined by their expectations concerning the impact of innovation on the competitiveness of the technology they are currently using (Rosenberg, 1982, p. 107). If they perceive that technological uncertainties in the pre-salt technological trajectory can be hardly evaluated, they will most likely postpone their innovation efforts or even renounce to innovate. Their expenditures with R&D will be low and directed to technological improvements on mature technologies to keep their competitiveness afloat, probably importing new machines with embedded upgraded technologies.

![Figure 8: Risks and opportunities of technological development](source: Own assessments)

Firms operating in the second quadrant face the risks of putting a large amount of capital at risk (Kalecki, 1937). Their innovation efforts will be driven by the perception that specialization on particular equipments or services for the oil industry can provide substantial economies of scale. Technological cooperation agreement that shares costs and benefits of managing the technological uncertainties are certainly a strong incentive
for their innovation (Celly, et.al, 1999, p.p. 297). However, it must be taken into account their aversion to be largely dependent of a single buyer (Petrobras).

Firms operating in the third quadrant face the risk of “missing the pre-salt band wagon” but risks to innovate to supply the pre-salt specific demands are high as well. The question here is to what extent are domestic suppliers able to research new technological concepts and to evaluate the technological risks involved in the pre-salt? So far, innovations in the oil technological frontier have been a joint effort of Petrobras, multinational suppliers and foreign research centers because there was not enough domestic knowledge bases to move innovation beyond mature technologies. The challenge here is to develop the domestic knowledge bases and to link them to the NSES as a part of a network of innovation for the oil industry.

Firms operating in the fourth quadrant face large commercial risks to innovate in technologically convergent markets (economies of scope). Their products and services are not specific to the oil industry and they are not likely to have a large demand of Petrobras. Among these firms, the relatedness of the knowledge base is a key aspect to be considered (Breschi, Lissoni e Malerba, 2001). Although the commercial opportunity can be relevant, investments face risks and the expected benefits have to be measured against actual costs.

So far, Petrobras has concentrated its support for risk management among the NSES firms operating in the second and third quadrants but limited to the company idiosyncratic technological needs. This policy created a domestic NSES strongly dependent of the Petrobras, unable to compete internationally. Moreover, the technological and industrial spin offs of the BIOG to the Brazilian economy are lessen by the concentration of the domestic NSES in the supply of mature technological products and services. This situation severely limits the benefits of the BIOG for the Brazilian society.

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34 Most of the empirical studies of patterns of diversification refer to the notion of “technological proximity” in explaining diversification in output (Pavitt, 1984).

35 “In so far as mature products are precisely those that have exhausted their technological dynamism, this choice implies a clear risk of getting “fixed” in a low wage, low growth, development pattern” (Perez & Soete, 1988).
5. Conclusions

The pre-salt opens a large window of innovation opportunities for the BIOG. In the past, Petrobras innovation policy has been driven by the demand pull approach. Using the Learning by Using approach the company develop technological capabilities that allowed its progress from an imitative to an active innovation policy in close cooperation with international suppliers of equipment and services. However, the NSES has not acquired the technological capabilities to follow the Petrobras innovation policy as yet.

Recently, Petrobras discovered several super giant oil fields in the Brazilian pre-salt. The company planning for the development of these fields indicates that the BIOG is initiating a new phase with a large window of opportunities to improve its innovation performance, exploring economies of scale in particular. To produce the pre-salt oil, Petrobras can move through different technological trajectories but only the path breaking trajectory can put the company at the technological frontier of the oil industry eventually. However, the NSES is not prepared as yet to support Petrobras movement along this technological trajectory.

The continuity trajectory is the easiest innovation movement to do. It will produce large short term economic benefits but Petrobras will lose the opportunity to take the international leadership of the oil industry and Brazil will lose the opportunity to explore the spin offs of the BIOG innovation process to break through the vicious circle of low innovation, limited growth, relatively low income per capita.

A better alternative for both Petrobras and Brazil is to take the intermediate trajectory initially but signalling that it will head to the path breaking trajectory eventually. In this case, the innovation policy has to be structured under two pillars: one oriented to support the innovation intended to explore economies of scale among NSES firms that operates with mature technologies (move them to the second quadrant) and another oriented to search of innovations among firms prepared to articulate their technological efforts with development of the domestic knowledge bases (move NSES firms to the third and fourth quadrant). Developing these two pillars, the BIOG will end up with the knowledge bases and the innovation capabilities to take full advantage of the benefits of the pre-salt oil reserves.
This strategy demands a full review of the innovation risk management strategy used for innovation in the BIOG so far. Although the role of Petrobras remains important, government incentives for the development of the knowledge bases related to the oil business has to be strongly increased to reduce the pre-salt uncertainties and the oil innovation policy has to be concentrated on the mitigation of risks among the NSES firms as well. A new institutional arrangement is needed for the management of innovation risks with the objective of moving the focus of the innovation process from products and services to the flow of technological information among Petrobras (the leading technological user), the NSES firms and the domestic research community. It should head to the creation of a network of generation, diffusion and use of technologies for the BIOG that will produce a NSES competitive worldwide.

As latecomer, the pre-salt offers to Brazil a unique chance to catch up and forge ahead the technological frontier of the oil industry. In the early stage of the technological transition, the innovation policy can be concentrated in the exploitation of economies of scale (move to the NSES firms to second quadrant). At a later stage, the adoption of the technological systems approach that looks beyond the current technological needs, with prospective (ex-ante) vision, would be the critical ingredient for technological progress.
Annex 1

Figure 7
Historical CAPEX Real 1954-2009 (US$ MM)

\[
\text{Table 6}
\]

Petrobras Investments for the next years (US $ 2011)

<table>
<thead>
<tr>
<th></th>
<th>2011-2014</th>
<th>After 2014</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>E&amp;P</td>
<td>96,7254</td>
<td>252,5189</td>
<td>349,2443</td>
</tr>
<tr>
<td>Refining, Transportation, Distribution and Petrochemical Area</td>
<td>49,7481</td>
<td>36,5239</td>
<td>86,272</td>
</tr>
<tr>
<td>LNG and Fertilizers</td>
<td>10,7053</td>
<td>1,8892</td>
<td>12,5945</td>
</tr>
<tr>
<td>Biofuels</td>
<td>0,0793</td>
<td>0</td>
<td>0,0793</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>157,3048</td>
<td>290,932</td>
<td>448,2369</td>
</tr>
</tbody>
</table>

Source: Petrobras
References


