

The Catch-up Strategy of Petrobrás through Cooperative R&D

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ABSTRACT. This article seeks to reflect on the possibilities of cooperative R&D to constitute an opportunity for companies in developing countries to take part in the innovation concerning technological frontier. In order to show this thesis can be true, this article is based on the case study of Petrobrás, the Brazilian state-owned oil company, which has employed the resource of cooperative R&D to gain access to the new subsea boosting technology and to acquire a place in the vanguard of such technology. However, the catch-up occurs only when firms in developing countries actively take part in the innovation process and accomplish an efficient process of technological learning, which is reflected on the evolution of interactions with external partners. The experience of Petrobrás is analyzed emphasizing the technological learning process through the transformation in its agreements with external partners. We present three cases of subsea boosting technologies developed by Petrobrás together with a majority of foreign producers or institutes. The analysis of these experiences allows us to show that the learning process and the mastery of in-house processes were accompanied by a significant evolution in the agreements with external sources. Petrobrás passes on from the position of cosponsor to that of articulator of the innovation process in technological cooperation agreements. The article proposes an evolutionary sequence to analyze the company's learning process. The evolutionary trajectories are different in each case, but in all of them it was possible to prove the increasing commitment of Petrobrás to the innovation effort.

1. Introduction

The world oil industry is going through an important technological evolution in spite of being considered technologically mature. This evolution is conditioned by the spread of new technologies

(information technology and new materials) and by the need for finding out increasingly effective methods of locating, extracting and processing hydrocarbons more and more difficult of access in an international environment characterized by low oil prices.

Companies in this sector have been seeking to intensify the rhythm of generation and diffusion of innovations in order to be able to remain profitable and survive the constant oscillations and uncertainties which characterize this industry. In this context, the search for agreements among large companies and between large companies and their suppliers have been intensified. These associations have proved suitable for suppliers of goods and services and for oil companies to cut down innovation costs, which tend to increase according to economic uncertainty. Such associations, an already common pattern in this business, where the relation user-supplier has always been very important, expanded considerably and reached a global scale.

This change in the pattern of research organization on an international scale is offering new opportunities in developing countries for companies with good technological base to acquire a place on the technological frontier, formerly exclusively controlled by a select group of leading developed countries.

To exemplify this thesis, we will use the case of Petrobrás, the Brazilian state-owned oil and gas company, which has been standing out as a leader in the deep offshore technology. Thanks to new modalities of relationship in the oil industry, this company has managed to join the small group of companies which are developing subsea boosting technologies in the 1990s. However, such catch-up must be placed within the framework of the company's learning process.

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To approach this theme, the article seeks to define in the first item the forms of strategic agreements existing in this industry, pointing out among them the importance of cooperative R&D. We discuss the relevance of such agreements to the catch-up of developing countries and emphasize the role of various forms of agreements in these companies' learning processes. In the second item, we present the dynamics of offshore oil industry and the importance the subsea boosting assumes as a new paradigm of production in deep waters. In the third item, we present the trajectory of Petrobrás in the offshore production, highlighting the three concepts of subsea boosting in which this company decided to invest. In the fourth, fifth, and sixth items, we describe the evolution of Petrobrás in these three concepts and the various forms of agreement employed to establish relationships with foreign R&D companies and/or institutions. The seventh item brings about a reflection on the learning process Petrobrás has accomplished in each of the concepts and analyzes how these different forms of agreement have evolved along this process. Finally, in the eighth item, we show the main conclusions of this article.

2. Strategic agreements and catch-up of companies in developing countries

Strategic agreements between companies are more and more frequent ways of organizing innovation in industry, mainly in the high technology sectors (information technology, new materials and biotechnology). Mouline gives us the following definition: "...the agreement term has a very precise meaning: it is a matter of long and medium-term relations established between firms to share a limited set of resources of various nature (financial resources, equipment, technology, etc.), without questioning the autonomy of the firms involved" (Mouline, 1996, p. 2). Relationships between companies in order to innovate can vary deeply. The relationships, which can imply control of capital or not, are defined as follows: "mergers and acquisitions, production, exploration joint ventures, joint R&D, codevelopment agreements, technology swaps, technology licensing, exclusive market or manufacturing rights, second sourcing, comarketing agreements,

and exclusive purchasing agreements" (Vonortas, 1998, p. 186).

The importance of strategic agreements is not restricted only to the high technology sectors, more mature sectors are also witnessing the growth of this new form of organizing innovation (Hagerdoorn, 1995). Very complex equipment and systems necessarily require for their operation, conception, manufacture, and implementation the presence of a great variety of agents who act in a coordinated and cooperative way (Hobday, 1998).

This paper will only focus agreements between firms and/or research institutions which concern R&D. They represent only part of the new relationships that are growing within the framework of the industry. The activities which usually fall into this category are limited to what is defined by the Frascati Manual as R&D (basic research, applied research and experimental development), to which we should add industrialization and commercialization/implementation of the first series (Chen, 1997).

There is a wide range of advantages which justify carrying out R&D in a cooperative way: it allows sharing innovation costs between partners; it rationalizes the use of resources joining works before carried out individually and in a duplicate way; it makes network economies possible assuring, from the beginning, a greater number of customers; and it acts as a way of lowering the barriers against the entry of new incomers.

On the other hand, cooperative R&D involves certain disadvantages related to the difficult appropriability of innovation gains, opportunistic behaviors of nonparticipants and participants in the agreements, and difficulty of transferring knowledge among the participants of a project.

The difficult appropriability of innovation gains is leading to a legitimization of the State's support to cooperative R&D (Quintas and Guy, 1995). The public support in this activity is justified, because it is a powerful generator of externalities. However, the lack of appropriability does not necessarily mean that cooperative R&D is oriented to basic or precompetitive research. Some studies indicate that the most frequent forms of cooperative R&D are at the stages of development and commercialization (Chen, 1997). Even so, industry has shown an increasing interest in financing this sort of undertaking by itself.

This form of technological cooperation, even being a generator of externalities, always offers an opportunity of reappropriation through, for instance, the diffusion of knowledge among suppliers and a fall in prices and/or an improvement in input quality. Cooperation between customer and supplier to achieve technological development is quite frequent in oil industry and it tends to follow the model described by Hobday (1998) concerning complex equipment or systems.

Cooperative R&D could lower barriers to entrance both on technological frontier and on more mature technologies, acting as an opportunity for firms in developing countries. Thus, the ongoing transformations in the way of organizing R&D at the world level would offer new opportunities of catching-up for developing countries. However, this thesis is very controversial. Freeman and Hagerdoorn (1994), based on a database of inter-companies technological agreements undertaken during the 1980s (80–89), argue that companies in developing countries still hold a very limited position in the formation of innovators' networks on a world scale, although they recognize this position has improved. Vonortas (1998) counter-argues that, even in a limited number, these agreements have a great importance for developing countries and are growing openly.

In our opinion, the catching-up process developed by means of strategic technological agreements depends on the way companies in developing countries become able to advance through the learning process stages. To be successful, this process requires an increasing dose of in-house effort to act as a counterpart in the agreements. This effort requires that local firms are really interested in the technological development and have enough economic size to be able to support them.

In parallel, agreements with external sources tend to evolve. The evolutionary and dynamic aspect was little discussed in the studies on strategic agreements which analyze a great variety of agreements (Freeman and Hagerdoorn, 1994; Vonortas and Safioleas, 1997).² In order to understand better the evolutionary process, we think it is convenient to separate, even within the subset of strategic technological agreements, two different groups of agreements, following the guide-

lines suggested by Freeman and Hagerdoorn (1994).³

The first group includes patent, brand and know-how licensing agreements, service contracts, and other forms employed by developed countries to sell to developing countries the technological services which imply the transfer of an already commercialized technology. The second group is constituted of agreements, contracts, and projects of technologies which still are at an experimental phase on world scale. This group is really concerned with cooperative R&D. Into this category fall consortiums or joint industry projects, bipartite and tripartite agreements of R&D, and agreements with university/institute.

In our view, the participation of companies in developing countries in the second group of agreements is an important indicator of their level of technological capabilities. However, even within this category there are different modalities of agreement, which can reveal the changes which are occurring in these companies' technological learning processes. Therefore, it is convenient to identify the existing differences among different modalities of contracts and various forms of participation.

What distinguishes the joint industry projects from the R&D agreements is that, in the first case, the project is developed in a consortium with a quite wide range of companies. These consortiums are made up of the institution responsible for carrying out the project and the cosponsoring participants. They make possible for participants, by means of cosponsoring a project, to have access to its outcome and to be able to guide the project according to their needs. This latter function is taken over by a "steering committee" presided over by the agent of the consortium and constituted of participants. In general, the collective nature of the appropriation of the outcome of joint industry projects endows them with a calling for a sort of precompetitive R&D, but this is not always the case.

R&D agreements, in turn, have a scope much more defined by the client who contracts a research. This kind of agreement is sponsored almost exclusively by the client who, in turn, has almost private rights over the use of a new knowledge. However, it is possible that there is a cer-

tain sharing of research costs and outcome between the parts.

3. Offshore technology and Petrobrás

Offshore technology is evolving constantly due to the need to produce oil and gas at increasingly water depths. Several concepts were developed in various regions of the world to face this challenge. The technologies which received greater incentive when the barrier of 400 meters depth was surpassed were the TLP (tension-leg platform) and the FPS (floating production system).⁴ TLP technology received greater support in the Gulf of Mexico, under the leadership of Shell Oil (American branch of Royal Dutch Shell), whereas FPS technology experienced its major expansion in the Campos Basin in Brazil through the action of Petrobrás. Up to this moment, FPS technology had more success to face the deep waters production challenge, although TLP follows the records of Petrobrás at a close distance (Furtado, 1998).

Deep offshore technology is still in a pre-paradigmatic phase (Sahal, 1982; Dosi, 1982; Teece, 1986). In this phase there are several competing designs, but no one truly dominant in view. This is due to the constant technological evolution, which generates huge uncertainties about the gains obtained with the use of technology, and to the fact that new challenges are faced by achieving production in increasingly deeper waters. In this context, a technology which serves for a certain depth may not be technically or economically feasible in greater water-depths or if the general conditions of production are considerably different from those to which it was firstly employed. This aspect could explain why in the deep offshore industry there still is a so great plurality of concepts being simultaneously tested and applied. They correspond to the specific social, economic and environmental conditions of each region or country.

Such aspects could explain why, beside the relatively consolidated designs, new radically concepts are being tested in this industry. The subsea boosting represents a certain kind of emerging radical innovation. The use of subsea boosting systems would permit an increase in the distance between the processing unit, located on the surface of the sea, on a platform or in a boat, and

the wellhead located on the seabed. Thanks to this innovation, it would be possible, depending on the context, to bring processing units to the continent or to shallower waters where their installation costs would be much lower. The subsea pumping, besides its revolutionary promises, has much more immediate opportunities for application. This technology relieves the necessary fluids pressure on the wellhead, which is always great in deep waters, to carry production to the platform. Thus, productive life of wells is lengthened and the hydrocarbon's recovery coefficient is increased.

4. Subsea boosting systems and cooperative R&D

Petrobrás, as a state-owned oil company, has almost always sought to develop the national oil production according to the country's needs, what has taken it to produce oil where reservoirs were available. A major part of such reservoirs are located offshore and in deep waters in the Campos Basin in the State of Rio de Janeiro. The singularity of the challenge of producing oil offshore and, later, in deep waters has faced Petrobrás with the need to stop being a company which essentially absorbed external knowledge to become an organization able to conceive its own technological solutions.

The development of concepts for deep waters (deeper than 400 meters) has occurred based on the introduction of successive improvements and adjustments to FPS in order to make it operational at such depths. This learning process was based on the following sequence: absorption of external knowledge → unbundling of technology → generation of solutions of its own, suited to deep waters in the specific conditions of the Campos Basin.

When Petrobrás diversified its technological bets and wanted to join the select group of companies which invested in subsea boosting systems, it had to change its strategy. It was not dealing with a established technology which could be acquired from an engineering company or from a foreign manufacturer to be unbundled later on and adjusted to the local conditions. Neither was it possible, not even in the beginning, to resort to the knowledge basis already consolidated at Petrobrás to create solutions. It was necessary to

associate with the other companies at a stage in which a technology was still being developed.

There was a great technological uncertainty in the oil industry concerning subsea boosting systems, and it was due to the competition among a great variety of concepts and to the high costs of innovation. These factors pointed to the need of conducting this effort in an associative way. The uncertainty inherent to technology was worsened by an unfavorable environment to new investments, which began to take effect in this industry from the 1986 oil counter-shock on. In this context, it was necessary to share risks to be able to continue to develop concepts still little tested, mainly if we take into account the great variety of concepts of subsea boosting systems which have been developed at an experimental phase since the early 1980s. The subsea boosting technology was still at a preparadigmatic phase in several simultaneous and opposing designs. When Petrobrás joined the club of companies which operated in the subsea boosting field, it invested in nothing less than three different concepts, each holding a certain range of different competing technologies.

The way Petrobrás has found to associate with other firms in its innovation effort varied according to the stage reached by the learning process in its research and operational teams. This process made a sensitive change in the company's external relationships possible. It passed on from the traditional technology transfer agreement with foreign suppliers to several forms of technological cooperation agreements. These forms of cooperation included different degrees of sharing innovation costs and of external and in-house involvement in the innovation efforts.

The cooperation agreements were a key means for Petrobrás to achieve a *catch-up* in subsea boosting technologies. Through these agreements this company could have access to the technological frontier knowledge at its precompetitive phase. Simultaneity and access to information from bodies directly involved in innovation have been important learning mechanisms. Nevertheless, learning was proportional to in-house effort. Thanks to such effort, Petrobrás became an important interlocutor in the generation and proofing of new concepts.

To illustrate the learning process of Petrobrás, we will take as example three initiatives of devel-

opment and application of subsea boosting systems:

- subsea multiphase flow pumping system (SBMS)
- subsea separation system (SSS)
- electrical submersible pumps in subsea wells (ESPS)

They are three different processes with very similar functions, pumping several fluids from a well to a process unit. Each one of them represents a different strategy of Petrobrás to master these technologies.

5. Subsea multiphase flow pumping system (SBMS): a successful catch-up strategy

Petrobrás decided to bet in the SBMS in the second half of the 1980s, within the scope of the Technological Development Program on Deep-water Production Systems—Procap 1000. At an international level, this technology was less established. There were several different concepts being developed by several actors (oil companies, equipment manufacturers, research institutes) in an associative way. There was a great uncertainty about SBMS becoming a viable alternative and about what concept was the most promising. Moreover, Petrobrás had almost none previous knowledge of this technology.

The strategy Petrobrás adopted was to join a joint industry project led by the Scottish manufacturer Weir Pumps for developing a sparrow kind of volumetric pump. It mobilized an engineer full time to accompany the actual advances made by the joint industry project and organize the activities related to the innovation project for using subsea multiphase pumps. The route of Weir Pumps eventually revealed to be a technological failure. Certain problems concerning elastometric materials could not be solved. However, the project became an important learning tool for Petrobrás. This company could have access to state-of-the-art subsea multiphase pumps and connect to other groups operating in this field. At the end of the project, it already had a much deeper knowledge of which were the most promising technologies.

Because of this learning, the company assumed a much more active posture in the SBMS technology, and from then on became an important partner in the technological developments at an international level. After the end of the joint industry project with Weir Pumps, Petrobrás began to contact important foreign partners viewing the implementation of a prototype in Brazil.

First, Petrobrás has unsuccessfully sought to import from the French Institute of Petroleum the concept of the helico-axial pump, the most tested one, in order to adopt it on a platform in the Campos Basin. This strategy proved wrong, due to the French institution reluctance to make this technology available in Brazil. It became apparent that Petrobrás would not gain easy access to this new technology without taking over a greater commitment to the innovation process.

In order to proceed with its intention to join the select group of companies which operate in the SBMS field, Petrobrás had to take over a more and more active posture. In 1993, it established a technological cooperation agreement with the German company Borneman to develop through testing campaigns a prototype which could be operational in the production conditions in the Campos Basin. This agreement involved the acquisition of a prototype of a multiphase volumetric twin-screw pump from Borneman at production cost. This kind of pump was the most adequate to the conditions in which Petrobrás initially intended to adopt this concept (Caetano et al., 1997a).

The more active posture before innovation was rendered effectively concrete through the company's engagement to construct a test site for subsea pumps in Atalaia, near Aracaju (northeast of Brazil), which was completed in October 1994. After a testing campaign which lasted over 6,000 hours, Petrobrás together with Borneman's technicians got to identify and solve the main technological bottlenecks, in order to make the pump operate in adequate safety conditions. In 1996, Petrobrás had already mastered this technology and decided to implement it in a production site.

The first adoption of a multiphase volumetric pump by Petrobrás occurred on the sea surface, on the Moréia fixed platform in the Campos Basin in 1996, employing a Borneman equipment. However, the company's real technological chal-

lenge consisted of installing this kind of pump in deep waters offshore. In order to achieve it, it was necessary to develop, besides the pump, a whole system of subsea production. Petrobrás decided to build and implement SBMS-500 (Subsea Multiphase Pumping System) in association with a set of foreign manufacturers (Caetano et al., 1997b).

In June 1997, it was launched a joint industry project headed by Petrobrás and by the Westinghouse Electromechanical Division to build and implement SBMS-500. Westinghouse was in charge of the construction of the electrical engine and Leistritz, a German supplier, was in charge of the pump. A series of other suppliers took part in the project covering areas as subsea cables and risers, connectors, sensors, etc.

The shift of pump supplier from Borneman to Leistritz has not represented a deviation from the technological route. Both produce the same kind of multiphase pump. This shift has only meant a choice to rearrange partners after the conclusion of the first testing phase of the pump. Petrobrás considered more convenient to associate with a new supplier due to differences in cost.

In the SBMS 500 joint industry project, AMOCO, Chevron, Oryx, and Hardyoil joined as contributors. The system is to be installed and will begin to operate in a well of the giant field of Marlim, 730 meters deep, from October 1998 on. The forecast increase in production is around 600 m³/day.

In the case of SBMS, the involvement in cooperative R&D projects has greatly contributed to the technological learning process in house. The joint industry projects and the bilateral agreements were highly important to the company to evolve from an initial stage of an almost lack of knowledge of the technology to one in which it started to conceive its own systems. Initially, the joint industry projects were the entry for Petrobrás to be able to monitor the major progress in the sector. After having identified its target, Petrobrás invested heavily in the technological development constructing a test site of its own and carrying out testing campaigns in a prototype. At this stage, the adopted strategy was to establish a technological cooperation agreement with the manufacturer of the pump. Finally, after having mastered the critical parts of this technology, Petrobrás pursued the conception and implementation of a

SBMS suited to deep waters. At this stage, the joint industry project was employed again, but, at this time, to share innovation costs with companies interested in having access to the knowledge the project was generating.

6. Subsea Separation System (SSS): Difficulties with an endogenous technology

SSS is a concept similar to multiphase pumping. Both have aroused the interest of large oil companies. Petrobrás was soon more directly involved in SSS than in SBMS, because the technology of the former system, which uses conventional components, was within easier reach.

A great variety of concepts coexists in the set formed by all SSS. Petrobrás, following a certain nationalistic logic in action during the 1980s in Brazil, and due to the lesser technological barriers to entry, decided to bet on its own technological route. It developed a concept in which the separator, the sensitive technology of this system, is powered by the pressure of the gas injected from the platform. There is no pump in this case. This system, "Petroboost," was patented in 1987.

Because of this initial success, Petrobrás decided to support the effort for developing an SSS suitable to deep waters. An important team of engineers was designated to develop the "Petroboost" technology from patent to a stage of industrial prototype. A system was prototyped at Cenpes (Petrobrás Research Center), proving its technical feasibility.

At the same time, Petrobrás started to closely follow the evolution of other technological concepts, tested or promising, which were emerging in the international scene of this industry. Such strategy of diversifying bets, outlined in the 1980s within Procap's scope, was really successful, for it allowed the Brazilian company to survive in spite of the great technological uncertainty in the field. Two concepts were closely studied: the conventional concept by Boet, from the United Kingdom, already tested in the North Sea, and a new concept, VASPS (Vertical Annular Separation and Pumping System), of which the originality was to connect a submersible centrifugal pump to the separator.

The concept of the Petroboost did not thrive eventually. When Petrobrás decided to build a

prototype and test it on real scale, it faced serious problems. First, it had serious difficulties to find home suppliers able to produce key equipment components such as high cycling valves. Tests carried out at Petrobrás research center did not approve home-produced valves. Consequently, Petrobrás had to look for the products that met its technical specifications abroad. However, Petroboost project did not interest foreign manufacturers. After an invitation for a bid for building a prototype, the company obtained only one answer, from an American manufacturer, at a price three times higher than what was being expected, what made its implementation in industrial scale economically inviable. Facing manufacturers' lack of interest, Petroboost technology was eventually abandoned.

Boet's system was also put aside after a try to establish a technological cooperation agreement with this British company. It offered little economic appeal, showing clearly the conventional systems lack of viability.

The concept of VASPS has shown more vitality. This more recent concept is based on a helical vertical separator coupled to an electrical submersible pump. This technology was conceived by British Petroleum and developed by Baker-Jardine in the United Kingdom. The first phase of development in this process was sponsored by a joint industry project supported exclusively by Conoco. In 1992, the second phase of the contract started, and a higher number of oil companies joined the project: Agip, BP, Conoco, Elf, Mobil, Shell, Statoil, and Petrobrás. The joint industry project would allow Petrobrás to gain access to this technology. However, the sort of participation Petrobrás has chosen, solely as a cosponsor, generated a certain dissatisfaction in the company's research team, which had access only to results and not to the theory.

Such dissatisfaction concerning the joint industry project made the Petrobrás team to seek to develop in parallel its own concept of VASPS, associated with a Brazilian university: Unicamp. The project with the Mechanical Engineering College of Unicamp was really fruitful and generated important results. Unicamp team set up a laboratory where VASPS was tested on a prepilot scale. As a result of this learning process, important alterations were made to the British concept

of VASPS. The team Unicamp-Petrobrás developed an original concept of VASPS, which resulted in two patents and several master's and doctoral theses. Due to the promising results of this partnership with the University, Petrobrás decided to support simultaneously the construction and the test of the prototype by Unicamp-Petrobrás and Baker-Jardine. The two prototypes were tested at Agip's site, in Italy, and in Aracajú, Brazil, within the framework of a new joint industry project. The testing campaigns permitted proving that both prototypes had met the technical operating requirements. Because of such success, Petrobrás decided to implement experimentally both concepts of a VASPS pump in the Campos Basin in 1999.

In the case of SSS, Petrobrás has taken over, from the beginning, a more active and endogenous posture in the innovation process. The fact that the technology was more accessible, due to the use of conventional components, explains in part the company's posture. However, this strategy was not successful, because Petrobrás betted on a little promising concept. Moreover, it did not know how to involve manufacturers in the innovation process in an effective way, what was fatal when it had to transfer technology to the manufacturer.

Thanks to the prudent posture of monitoring other types of SSS, Petrobrás has succeeded in passing on to an alternative concept when it realized that its own concept would not thrive. The joint industry project had a major significance to make the company able to carry out this change of technological trajectory. Thanks to this kind of cooperation, Petrobrás could obtain firsthand information related to the development of VASPS, which represented a quite new concept for it. However, this modality of agreement, in which the company takes part as an observer, did not permit it to master the *know-why* of the technology (Lall, 1982). In order to overcome this hindrance, a new type of association became necessary. The research agreement with a university was useful for the company to reach a greater control over the new technology and to develop its own model of separator. However, the development of its own concept was integrated in a new joint industry project, in which it was competing with the British concept. It shows that the

company has adopted a much more opened posture with regard to the development of its own technology, exposing it to competition and framing it within collective decision-making structures, such as the joint industry projects.

7. Electrical submersible pumps in subsea wells (ESPS): Contracting-out as a shortcut to innovation

ESPS is a concept similar to SSS. The difference with regards to the latter is that it dispenses with the separator. Its originality consists of a down-hole electrical submersible pump inside a well, whereas in the previous examples the pump is outside the well. This system started to operate as a substitute for *gas lift*.⁵ Therefore, it is a more modest application of the subsea boosting technology, which aims at substituting for the existent technologies.

Petrobrás became interested in this concept only during this decade. On the other hand, the company was extremely fast to adopt it. When Petrobrás became interested in this technology, it was already available. However, it was not being adopted to subsea wells yet. The great challenge was to make the electrical pump and its auxiliary equipment marine.

Petrobrás has quickly answered that challenge. First, it analyzed the techno-economic viability of adopting the ESPS in subsea wells. This study allowed it to identify the existence of a niche to adopt this technology in subsea wells located at a distance of some kilometers from platforms. It carried out tests in key components as cables and connectors. It soon identified a well in which the prototype could be adopted, and the operational departments approved the project. As a result of this approving, Petrobrás found, in early 1994, major manufacturers and organized a technological cooperation agreement with them. Tronic (connectors), Reda-Lasalle (pump, engine, sensor), Pirelli do Brasil (cables), Sade-Vigesa and Cooper (alterations in the wet Christmas tree-WCT) took part in the agreement, aiming at installing the prototype at a depth of 300 meters and at a distance of 500 meters from a platform in the Campos Basin. The greatest efforts were the development of connectors and subsea electrical cables, for which Tronic and Pirelli do Brasil

were responsible. Petrobrás was in charge of all other components, including providing the WCT, installing *flowlines*, and project building, installing, and management. The time taken to innovate was very short, since a pump was installed in a subsea well and started to operate from October 1994 on (Cactano et al., 1995). That was the first electrical submersible pump to be installed in the world. The average well flow was relatively modest, 116 m³/day. This well has operated for almost three years and stopped in 1997 due to a failure caused by an obstruction in the system.

Encouraged by operational success, Petrobrás has decided to continue investing in this technology. The next technological challenge, represented by the deep waters program, Procap 2000, was to take such equipment to a depth of 1,109 meters, at a distance of 6.5 Km from a platform in the Albacora-East field.

The challenge represented by deep waters demanded that Petrobrás wove a new web of external relationships. Contrary to the shallow waters system, which had just a pump coupled to an engine inside a well, the deep waters system needed a subsea power transformer which could operate at depths of up to 1,150 meters in order to receive high tension from the platform (10 thousand volts), transform it into a lower tension (3.5 thousand volts), and transmit it to the pump.

Petrobrás, following the strategy designed at the first stage, has given a great importance to contracting-out to face the major technological bottlenecks derived from the adoption of this new deep water boosting system. The form of agreement employed to involve external participants was a technological cooperation agreement established bilaterally with the main manufacturers. The project of implementation of a ESPS in deep waters started with a first phase in 1995, in which Petrobrás tested the feasibility of the critical components of the system. Siemens of Germany was in charge of developing the transformer. The basic project of the Christmas tree, which is traditionally an equipment produced by home manufacturers, was agreed with an association between Sade-Vigesa (Brazilian) and Cameron (American), but had an intense participation of Petrobrás, which holds an important technical capability in this field. This is a new concept of horizontal wet Christmas trees (HWCT), suited to deep waters.

After the conclusion of the basic projects, a new stage of agreement to build a prototype began. Petrobrás has established technological cooperation agreements with almost all the main manufacturers:

- Pirelli do Brasil—development of power cables (10 Kv) suitable for deep waters
- Tronic—development of electric connectors
- Reda—development of electrical submersible pump and electric engine
- Cameron—agreement to manufacture the HWCT
- Siemens—development of subsea electric transformer

This new phase demanded that Petrobrás became even further involved in the innovation process, taking over the task of accompanying the manufacturing and testing of components such as power transmission lines and electrohydraulic risers, electrical submersible pump, connectors, etc. Nevertheless, the major part of the cost and risk of innovation went on being contracted out.

At this second stage of the project, a change in the relationship with home suppliers took place. Sade-Vigesa, which had taken part both in the adjustment of the WCT from the first project and the basic project of the HWCT for deep waters, was later excluded from their manufacturing. For several reasons, national manufacturers could not respond to the technological challenge posed by deep waters.

However, technological difficulties have not affected solely national manufacturers. Relationship between foreign manufacturers and Petrobrás faced some difficulties. Siemens of Germany, in charge of manufacturing the transformer, and Cameron, in charge of manufacturing the HWCT, failed to keep to delivery terms.

Therefore, the prototype has only been implemented in June 1998 (Mendonça, 1998), after a one-year delay according to the initial forecast. Even so, this feat represented an important innovation and a great technological success. With its implementation, Petrobrás broke the world record for ESPS adoption in deep waters. The 600-m³/day production achieved using the pump is significant and equals to that of the SBMS-500.

The electrical submersible pump located in subsea wells was the sort of technology which

made an extremely fast entry in the subsea boosting field possible. Resorting to a *contracting-out* strategy with equipment suppliers, Petrobrás has not had to disburse sizeable resources in home R&D in order to innovate. This strategy has been successful when the matter was to make a pump operate in shallow waters. However, it presented some additional difficulties when a leap to deep waters was required.

To build a prototype in deep waters, Petrobrás has had to redesign its framework of agreements. The unique home manufacturer was put aside, whereas Siemens was incorporated to manufacture the transformer. Petrobrás controlling costs increased highly as a result of the technological challenges posed by the project. Even so, Petrobrás faced serious setbacks to install the prototype in deep waters due to foreign manufacturers' difficulty to keep to delivery terms and to meet specifications. The most used modality of agreement was that of a technological cooperation with equipment manufacturers, almost all of them foreign. The strategy of *contracting out* faced greater problems when the technology was a really technological frontier. Even so, this strategy proved to be an interesting form of technological shortcut.

8. Technological learning process and forms of agreement

Each of the technological systems we have analyzed represents different strategies to join the select club of innovators in the subsea boosting field. In each case there was a considerable technological learning process, which made possible for Petrobrás to evolve from the stage of beginner to that of technological partner. However, this process followed different paths according to Petrobrás own strategies and to intrasectorial technological specificity.

The technological strategies and the learning process of Petrobrás can be understood through its ways of agreement with external sources of technological knowledge. The modalities of agreements, the way they are carried out, and the position of each actor are important elements to define the technological learning process trajectories of the company.

In general, there are three modalities of agreements, which have been used in technological

partnership:

- joint industry projects
- technological cooperation agreements
- research projects with universities.

The joint industry projects have had quite distinct functions according to the stage of the technological learning process of Petrobrás. In the beginning, they acted as a means of communication which allowed Petrobrás to have access to important information about frontier technologies, which were being tested by leading companies. Most of the time, the joint industry projects were financing testing campaigns which allowed the proof of the technical viability of a certain technology. This kind of participation made Petrobrás teams come in direct contact with the major technical problems which were in need of solution. At this stage, Petrobrás joined the projects as a cosponsoring agent which had privileged access to determined information, and could interfere in the course of the research. Such access spread, by means of an osmosis process, to other technologies and to a network of actors who were collaborating and competing on the technological frontier at a given moment. We will call this kind of agreement M1.

At a second stage, Petrobrás started to use the joint industry projects to share the costs of an innovation undertaken by itself. At this stage, it defined new concepts and adopted them in its own oil production fields. Those interested in cosponsoring this kind of project were, like Petrobrás, large oil companies in search of access to the technological frontier. The projects were carried out through partnerships with manufacturers, and later implemented in the Campos Basin, which acted as a laboratory for testing new technologies. We will call this kind of agreement M2.

The technological cooperation agreements (TCA) were essentially mechanisms of sharing risks between Petrobrás and manufacturers of capital goods. Through this kind of agreement Petrobrás has bought equipment, in general, at prime cost (with no overheads). Manufacturers took on the responsibility of observing the evolution of the tests and introducing improvements. These agreements demanded that Petrobrás took on a much greater responsibility for the running of the whole operation of building the system.

Research projects would be a third modality of external relationship, in which the partner was a university or research center. This kind of agreement was established, in general, at an earlier stage of the innovation process, which involved a greater content of technological innovation and basic research. In only one of the concepts Petrobrás resorted to this modality of agreement. These agreements correspond to more endogenous innovation strategies, in which the company takes on the major part of costs and technological risk.

To put it simply, we can classify the agreements Petrobrás established with its technological partners according to their degree of commitment with the innovation effort. From the simplest to the more complex, we have the M1, then the technological cooperation agreements, and finally the M2. This sequence was the most suitable for the learning process and allowed Petrobrás to take more advantage of the external sources of knowledge on this kind of technological frontier.

However, this sequence of learning was possible only because Petrobrás is a very large company, which is deeply involved in the innovation effort. Large amount of resources were affected in the innovation process and complementary operational capabilities were decisive for the launching these new concepts into production field. Economic size is a decisive variable for a developing country to become a real player in the new of strategic alliances. Only large companies are really able to benefit from this kind of learning sequence.

As we have mentioned, each one of the boosting technologies represents a strategy of its own and a different learning process. Table 1 shows the main forms of agreement established with external sources of technology at each stage of this process.

SBMS project is the closest to the ideal sequence of learning. It has started with an M1 to have access to state-of-the-art technology. Then, Petrobrás started to coordinate the innovation process itself, choosing the supplier which would develop a pump, with which it established a technological cooperation agreement and, at the same time, it took on an important part of the innovation costs when it built a testing unit for the prototype. After having mastered the knowledge, this company set up a boosting system in the deep

Table 1
Trajectory of forms of agreement in the subsea boosting projects

Project/Phases	Phase 1	Phase 2	Phase 3
SBMS	M1-----→ TCA-----→ M2		
SSS	EG-----→ † M1-----→ M1/M2 and EG		
ESPS	TCA-----→ TCA		

M1: joint industry project type 1

M2: joint industry project type 2

TCA: technological cooperation agreement

EG: endogenous generation

waters of the Campos Basin. At this third stage, it remade its framework of agreements and established an M2 with the aim of sharing, partially, the innovation costs.

SSS project has started with a greater participation of Petrobrás in the generation of technology. Such participation was a result of the formation of a research team, from the middle 1980s on, aiming at the development of this system, and of less technological complexity in SSS. However, the initial choice did not succeed, also because it had been made in an excessively isolated way from partners. What shows the great importance of associating with suppliers, without whom the success of an innovation is almost always really difficult to warrant. The company had to retrace its technological trajectory. On that occasion, M1 was an excellent opportunity to change to a more promising technological trajectory. However, M1 has also shown its limitations. In order to attain more advanced stages in the learning process, Petrobrás had to resort to a research project with a university. This relationship with the academic environment allowed it to achieve a technical mastery which was enough for the company to make the decision to implement an SSS in the Campos Basin based on a concept of its own, and it also allowed it to take a differentiated part in the joint industry project, closer to an M2.

ESPS project is quite different. Petrobrás has done pioneering implementation of a concept in the Campos Basin without having to go through the stages of the two previous projects. Such

success resulted from the greater availability of this technology and from the fact that the company took advantage of an opportunity. Petrobrás soon started to coordinate the process, resorting to technological cooperation agreements with suppliers to have access to external sources of knowledge. However, the strategy of *contracting out* started to present certain difficulties when the challenge was to proceed to deep waters. Therefore, in this case the difference was not only in the trajectory of the agreement form, which remained the same in the technological agreements with suppliers, but it rooted mainly in the way the division of labor took shape between external and internal sources of technological knowledge. The strategy adopted by Petrobrás was to let to suppliers the risk of innovation, contracting out all activities, including the testing ones. This strategy of *contracting out* proved to be the riskiest to greater technological challenges, as those produced by adoptions in deep waters. Nevertheless, it was successful, showing that this strategy can generate important results.

The success of the ESPS is certainly associated to the greater opportunities that emerged from the adoption of this technology. The difficulties faced were minor, demanding less internal commitment to the innovation effort. The lack of joint industry projects in this case is associated to a more downstream characteristic of this project in the innovation process. Indeed, joint industry projects are more often used at the precompetitive stage, when the degree of uncertainty tends to be greater and the adoption implies important technological challenges.

Technological specificities of boosting systems had great influences in the learning process shown in Table 1. These specificities almost explains the differences between the three case-studies. As a simplification, these specificities can be reduced to different stages in their technological trajectory. At the beginning of their trajectory, technologies are at an exploratory phase, and there exists a great uncertainty about their outcomes. At the other end, technologies are much more well-known, and changes are incremental to adapt to local situation and improve performance. Even at the exploratory phase, boosting systems designs show different stages of evolution. SBMS is closer to a technology at the beginning of the trajectory

while ESPS is a more mature technology, and SSS is in an intermediate phase.

The stage of the technological trajectory in each one of these systems shaped Petrobrás' learning process and technological strategy. The endogenous technological strategy was used only with more mature concepts, as illustrates the SSS case when compared to SBMS. However, that kind of strategy was not successful because even for more established concepts, the technological uncertainty is increasing. Therefore, actually the associative strategy seems to be the more adapted way to do innovation in frontier technologies.

The associative strategy was much more successful at the beginning as well as at the end of the technological trajectory. However, the nature of partnership evolved significantly. When technological uncertainty was larger as with SBMS and also with SSS, shared risks and decisions making through consortium were more appropriate, even followed by an increasing engagement of Petrobrás. On the other hand, when technology was more mature, contracting out third parties at the task level seemed to be the more appropriate strategy, even if at the end this strategy was problematic and required an increasing engagement from Petrobrás.

9. Conclusion

Strategic technological agreements include two modalities of agreements; the first is turned to licensing, and the second to cooperative R&D. Petrobrás way through the second modality of agreement with suppliers and/or competitors was an important path for it to join the select club of companies which deal with subsea boosting technologies.

Cooperative research acted as a way of lowering technological barriers to entry in areas where Petrobrás had little experience. The joint industry projects, particularly, were useful as instruments of access to relatively unknown technologies. In this sense the stage of a technological trajectory explains quite well the difference between contracting strategy of the three boosting systems. At the early phases when uncertainty is very high, cooperative agreements through consortiums were more adequate.

The consortiums were important resources to make Petrobrás able to face the high degree of risk existing in the subsea boosting field. Thanks to them, this company could get familiarized with a great variety of technological concepts. When the company experienced the difficulties involved in proceeding on a determined route, it had the chance to migrate to more promising concepts. Thus, this kind of contract seems to be an appropriate to companies to deal with the technological uncertainty of early stages technology.

The comparative analysis of these cases showed clearly that resorting to technology cooperation agreements was also a privileged mechanism of warranting the involvement of suppliers in the innovation process. In those cases this involvement did not occur, innovation ended up being aborted.

However, such partnerships have not always been lasting. There was a permanent redefinition of partners at each stage of the learning process of Petrobrás. Therefore, in spite of these agreements being strategic to reach certain technological knowledge and the network of innovators, they have not always been lasting. This conclusion agrees with that of another study on the cooperative R&D of Petrobrás (Miranda, 1996).

The degree of internal effort was another decisive element to the learning process of the company. When the degree of technological internal effort was significant, the company was able to master a technology and reach deep waters, as in the cases of SBMS and SSS. Even in the case of ESPS, a higher degree of internal involvement was also a necessary condition for the company to be able to progress and reach deep waters.

We could also confirm that the forms of agreement were being modified according to the evolution of the technological learning process. The joint industry projects were not the most important form of contracting out when Petrobrás took on the responsibility for the innovation process. Technological cooperation agreements started to be more frequent at that stage. In general, the joint industry projects were used as a starting point to gain access to state-of-the-art technology, and as a finishing point to share the innovation cost.

Less appropriability of consortium technology does not represent a significant problem for

Petrobrás, since the technologies researched concern productive processes that employ equipment of which manufacturing is, for the most part, contracted out from suppliers. On the contrary, it would be interesting that the technology spread as widely as possible, so as to transfer the innovation gain to users by means of competition.

The economic size of Petrobrás, along with its own innovative culture, was an important factor of success. Even if medium and smaller developing countries firms can take advantage of the technological alliances, larger firms with strong technological base are more able to present the kind of learning process that was analyzed in this paper.

Notes

1. The authors thank Nick Vonortas for his valuable comments to the early version of this paper.
2. The database studied by Freeman and Hagerdoorn (1994) embodies the technological strategic agreements in industry which include joint ventures, cooperative research, minority interests, R&D agreements, and *second-sourcing*. The criterion to approach this database was the technological content. Developing countries were in only 3.8% of the agreements. The technology transfer agreements were treated separately and had a slightly less accentuated concentration in the Triad. However, Vonortas' and Safioleas' study (1997) is founded on a wider basis which gathers a larger set of modalities of agreements ("mergers and acquisitions, joint ventures, R&D agreements, licensing, equity investment agreements, contractual agreements, standard coordination agreements, and university-industry cooperation") restricted to the sector of information technology. The participation of developing countries raises from 6 to 12% between 1984 and 1994. It is also true that this basis includes into the category of developing countries the former Soviet Union and Eastern Europe.
3. Freeman's and Hagerdoorn's study (1994) reveals that the agreements in which developing countries take part are proportionally much less destined to R&D, 13.4% for NICs and 12.5% for LDCs, than those established in developed countries, 50.3%. Furthermore, it separates the strategic-technological agreements from agreements which include any form of technology licensing or transfer.
4. TLP (Tension Leg Platform) is a platform tied up by tendons to the seabed, it makes possible to install the controlling valve system of well production, called Christmas Tree, on the sea surface, and FPS (Floating Production System) is a system of production based on a boat or semisubmersible platform connected to several Wet Christmas Trees (WCT), a set of valves on the seabed, by a web of flexible pipes and risers.
5. Gas lift is a system which increases well pressure by means of pumping gas from the platform. This system is widespread in the Campos Basin.

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