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Geographical proximity and innovation: Evidences from the Campos Basin oil & gas industrial agglomeration—Brazil

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ABSTRACT

This paper analyzes the results of an empirical study involving 10 firms located in the Campos Basin oil & gas industrial agglomeration in Brazil. Within the last 20 years, this region has emerged from limited oil & gas competencies to a leading center for deep and ultra-deep offshore exploration and production capabilities, resulting in Brazilian energy self-sufficiency. Firms operate under intense technological dynamism, providing technologically complex goods and services to major oilfield operators in that region. Firms analyzed included wellhead equipment suppliers ('wet christmas trees'), well service suppliers (well technology) and the highly influential national oil company, Petrobras. The analysis uses elements from the clusters and innovation systems approaches. The aim of this work is to determine the formation process and the actual characterization of the agglomeration and understand, from the perspective of the knowledge system and firms' technological approaches, how technological changes are implemented in the Campos Basin agglomeration and the origins of such changes. As a secondary objective, this study attempts to verify whether geographical proximity is a factor that favors innovation by the firms within the agglomeration. Results indicate the existence of a group of firms in which geographical proximity has a positive influence on innovative activities.

1. Introduction

In recent decades, the search for oil & gas fields has resulted in great technological advances in exploration, development and production segments, particularly in Brazil, a country that until 1974 lacked proven reserves to fuel their economy. Since that time, Brazil has emerged as one of the leading centers for offshore oil & gas production in deep and ultra-deep waters (i.e. between 1000 and 2500 m of water depth), a major achievement for any country, and a particular achievement for an emerging economy. Brazil is now energy self-sufficient, and differs from many resource-rich emerging economies by developing indigenous knowledge to find and exploit their reserves. This paper explores how this was achieved by analyzing oil & gas firms located in the Campos Basin of Rio de Janeiro State. Drawing on the clusters and innovation systems discourse, this study attempts to determine how the Campos Basin agglomeration emerged, how technological changes were implemented and to determine if geographic proximity is a factor that favors innovation by the firms located in the region.

Exploration and production (E&P) of oil & gas in deep and ultra-deep waters, once unimaginable, have become feasible due to substantial research and development (R&D) by oilfield operators and suppliers of offshore equipment by reducing the operating costs (Acha and Finch, 2003; Voola, 2006; Chandler et al., 2006; Tubb, 2007; Szklo et al., 2007). Some of the key technological challenges that the industry face include the following choices: the right equipment to be applied in a particular oil field/well discovery, appropriate production systems and structures and the availability of a technological base to carry out the project economically. In some cases, new technologies need to be developed to extract the resources.

E&P has faced several technological challenges in the last few decades and is consequently strategic for advancing offshore development in increasingly hostile environments. The complexity and the multidisciplinary knowledge required for solving these challenges and developing new production structures and systems have led firms within the Campos Basin to organize themselves as a geographical agglomeration of firms. This agglomerated structure evolves over time and is supported by a

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large supply network in which major oilfield operators play the role of the *anchor companies*. Like in other oil & gas regions, the concentration of firms is organized close to the oilfields, forming what is known as an *oil province*. The Campos Basin oil province consists of a geographical agglomeration of around 1500 oil & gas firms located in the Rio de Janeiro State. Of these, about 400 firms operate directly in offshore activities. Other firms support the larger suppliers and oilfield operators of the Campos Basin oilfields. The main oilfield operator is Petrobras, which has been able to undertake successful long-range strategic planning in order to be the reference actor in deep and ultra-deep water oil & gas production (Dantas and Bell, 2006).

This paper is an exploratory study encompassing 10 case studies of firms located inside the Campos Basin oil & gas industrial agglomeration. The theoretical framework draws on elements from the clusters approach and others from the innovation systems approach, specifically the sectoral (Malerba, 2004) and technological (Carlsson, 1995) systems approaches. These approaches were chosen because they provide a more complete explanation for the emergence of the industrial agglomeration and its peculiarities of being located in an emerging economy and exploiting ultra-deep water energy resources. The role of multinational companies (MNCs), peculiarities of the global resource industry and specific nature of the technologies under analysis were also identified as influential.

This paper focuses on technological innovation, the knowledge system and the firms' technological approach within the agglomeration. Two key dimensions constitute the core of this analysis: the knowledge system in a relatively small geographic area, which is related to clusters studies (Bell and Albu, 1999), and the firms' technological approaches, which are related to the innovation systems approach (Freeman, 1995). The geographical proximity focus and the sectoral and technological patterns are some of the elements targeted here. It begins with a review and critiques of the clusters discourse, followed by a similar discussion of the innovation systems literature. Key issues in global resource industries and the role of MNCs are then discussed, since the suppliers of technologically complex goods and services are usually subsidiaries of MNCs. A theoretical framework is then developed, followed by the methodology and details about the industrial agglomeration studied. The next sections discuss the result and analysis of the empirical study and the paper concludes with implications for research and policy.

2. The clusters approach

Since Marshall's (1920) pioneering work, many studies about the externalities of agglomerations have been conducted. Researchers and policy makers have classified agglomerations as industrial districts, *milieus*, clusters, networks, arrangements and systems among others. According to the 'Marshallian' metaphor in these agglomerated structures, knowledge is 'in the air', and connected firms absorb such knowledge naturally, without any explicit effort. Thus, according to him, knowledge is readily available as a public commodity. This means that in such agglomerations, there is a certain type of knowledge that, regardless of being acquired is freely available (Giuliani, 2004). Marshall (1920) defines this characteristic as an *industrial atmosphere* that benefits all firms located within the agglomeration. He states (p. 271) "…mysteries of trade become no mysteries; but are as it were in the air, and children learn many of them, unconsciously".

Following Marshall's reasoning, Porter (1990) developed the concept of *industrial cluster* that is now popular in policy and corporate circles, and there are numerous empirical studies and conceptual definitions within the academic discourse. For example, Batheld et al. (2004) suggest the existence of *local buzz* of high quality and relevance leads to a more dynamic cluster. Buzz refers to the information and communication intensity observed through face-to-face contacts and interactions of people and firms within the agglomeration. Also, a well-developed system of *global pipelines* connecting the local cluster to the rest of the world is beneficial for the agglomeration because each individual firm can benefit from establishing knowledge-enhancing relations to actors outside the agglomeration and the knowledge that one firm acquires through its pipelines can spill over to other firms in the agglomeration through local buzz.

There are several reasons for the importance of geographical proximity in the overall transformation process of the firms as well as of the agglomerations themselves. The challenge behind understanding how a cluster may benefit from, and sustain, international competitiveness lies in analyzing how the clusters can develop linkages to control the sources of specialized knowledge, wherever they exist around the world (Malmberg, 2003). Agglomerated firms within related sectors may increase the capacity to create knowledge and an intensified division of labor. The interactions between economic activities and local institutions make the agglomeration more attractive and the value created may justify the additional cost (Maskell, 2001).

However, with popularization the clusters concept also drew criticism within the literature, specifically the multiplicity of typologies, terminologies and conceptual confusion. Different typologies of clusters can be found in several works (for example, Amin, 1994; Humphrey, 1995; Markusen, 1996; Storper, 1997; Cassiolato and Lastres, 2001). Martin and Sunley (2003, p. 10) also note that there are several definitions of industrial clusters have led to a major source of ambiguity: "Because Porter's definitions are so vague, in term of geographical scale and internal socio-economic dynamics, this has allowed different analysts use the idea in different ways to suit their own purposes", leading to conceptual and empirical confusion. More generally, Langford and Hall (2007, p. 2) observed that studies conducted by for example Florida (2002), Martin and Sunley (2003), Garnsey (1998) and others "have been critical of the cluster concept, arguing that it is overly simplistic, with causal factors difficult to identify and results which cannot be evaluated".

According to Marceau (1994), an appealing attribute of clusters is that they can provide *positive externalities* to agglomerated firms, because they are interconnected and would theoretically encourage information and collaboration flows among cluster members. Some empirical studies confirm this assumption, although they deal with specific agglomerations in innovative countries in the Northern Hemisphere, such as Audretsch and Feldman (1996), Bender et al. (2002) and Aharonson et al. (2004). However, those three works also identify some *negative externalities* that, in some cases, can emerge in such a way that overcome the positive externalities generated by agglomeration of firms. Martin and Sunley (2003) also point out several *claimed advantages* and *potential disadvantages* of industrial clusters. Furthermore, many scholars provide empirical evidence (from different industries) indicating that the economic activity within geographically agglomerated clusters on its own does not represent any advantage for the firms located there. Indeed, some empirical studies point out an abundance of *non-dynamic*, *non-mature*, *static*, *declining*, *out-of-date*, *quasi-dead*, *stagnated*, *dead* clusters (Malmberg and Maskell, 2002; Martin and Sunley, 2003; Beaudry and Breschi, 2003; Batista and Swann, 1998; Boschma, 2004).

Malmberg (2003) lists three reasons for the asymmetry between the *promising* clusters theory and the *disappointing* empirical studies, such as: transactions among firms within a

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cluster are generally limited and collaboration is merely formal, intense local competition actually exists in some occasions and firms within a cluster acquire significant useful knowledge about one another, even though they often may not know where such knowledge originated or how important it is.

Regarding cooperation among firms, the majority of studies identify the existence of many *vertical cooperation linkages* in clusters along the production chain. However, the same studies stress the *irrelevance or even the non-existence of horizontal cooperation linkages* between firms without any relationship through the production chain, illustrating the scarcity of those linkages in reality (Schmitz, 2000; Malmberg and Power, 2003; Lee and Park, 2006). For Schmitz (2000), competitive pressure inside agglomerations is one of the most important reasons for the decline in horizontal cooperation.

According to Giuliani and Bell (2005), *knowledge within a cluster is not in the air*; rather it is directed towards those firms with better capacity to grasp it. Schmitz (2000), Schmitz and Nadvi (1999), Malmberg (2003) and Giuliani et al. (2005b) criticize the clusters approach because of the *exaggerated attention given to the internal linkages and almost none for external ones*. For those authors, extra-cluster linkages must also be focused if a sustainable, long-term analysis is to be made (for benefits of external linkages see also Du et al., 2007; Mansury and Love, 2008).

Other studies identify some other limitations of the clusters approach, such as the lack of satisfactory empirical validation of the theoretical mechanisms, the absence of a solid theoretical framework, and the absence of an industrial clusters theory in which knowledge is the central element (Malmberg, 1997; Maskell and Malmberg, 1999; Maskell, 2001; Malmberg and Maskell, 2002). Schmitz and Nadvi (1999) stress the need for studies that draw conclusive comparisons among clusters directed toward knowledge-related aspects.

However, in spite of the severe limitations, the clusters approach is still an important tool to address issues such as the importance of the geographical proximity for firms in a specific industry. However, the innovation systems approach, more particularly the sectoral and technological streaming, is also useful in this analysis in order to catch the sectoral and technological patterns observed in the industrial agglomeration studied.

3. The innovation systems approach

Freeman (1987) conceptualizes innovation systems as the network of organizations (firms and non-firms) in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Many different approaches derived from the traditional innovation systems concept have been developed some of which identify the geographical element as a fundamental feature, and to some extent may overlap the clusters approach. Thus, innovation systems studies may be spatially bounded, such as: *Transnational Innovation Systems*, i.e. limited by multi-national boundaries, for example *Mercado Común del Sur*—MERCOSUR or North American Free Trade Agreement—NAFTA (Whitley, 2006) and *National Innovation System*, i.e. limited by national boundaries (Lundvall, 1992; Nelson, 1993; Freeman, 1995). It may also be based on *Regional Innovation System*, i.e. limited by regional boundaries within a single country (Cooke, 1992; Cooke et al., 1998; Cooke, 2006) or *Local Innovation System*, i.e. limited by local boundaries (Brusco, 1996; Courlet, 2001). Innovation Systems may also be spatially unbounded, such as *Technological Innovation System*, i.e. bounded by a given technology (Carlsson, 1995; Carlsson and Jacobsson, 1997), *Sectoral Innovation System*, i.e. bounded by a given sector (Malerba and Orsenigo, 1997; Malerba, 2004); or *Corporative Innovation System*, i.e. bounded by a given corporation or firm (Granstrand, 2000; Granstrand and Lindmark, 2002).

Like clusters, there has also been criticism of innovation systems approaches. Albuquerque (2007) addresses some problems of the national innovation systems approach in developing countries and divides national innovation systems in two categories: *mature* (those observed in developed countries) and *immature* (those observed in developing countries). In his view, innovation systems should be able to prosper from the bottom-up to address specific local problems that intersect with specific sectoral problems. These criticisms can also be extended to other innovation systems approaches that include geographical proximity features, such as transnational, regional and local innovation systems.

Moulaert and Sekia (2003, p. 293) argue that "the theory of regional innovation systems insists on the role of collective learning, which in turn refers to deep cooperative relationships between members of the system". For them (p. 293) rather than a result of a conscious and joint research activity, "innovation is a creative process, with the following features: the interaction between agents of the process (built on feed-back); the cumulative aspect of, and increasing returns to, the innovative process; and the 'problem-solving' orientation, which shows the specific nature of the innovation". The regional innovation system approach can be interpreted at least two ways: it can be seen as "a subsystem of national or sector-based systems; or as a reduced version of the national system of innovation, with its own dynamic" (Moulaert and Sekia, 2003, p. 293).

Doloreux and Parto (2005) go further in their criticism by recognizing some important points still unsolved, such as definitional confusion and lack of empirical validation, and more specifically the meaning of region, the lack of attention to the central role of institutions, which represent the social relations. For them, a fundamental problem in all regional innovation systems studies is that it is not possible to determine how a regional innovation system might look in reality. They pose the questions (p. 138): "how much and what type of innovation must occur within a region for it to be considered a regional innovation system? Do all regions that aspire to take a lead in organizing and innovating become regional innovation systems by default?" Those questions are also valid for other spatially bounded approaches.

The innovation systems approach, however, may be characterized as myopic regarding technological transitions. The success of innovations is mainly regarded as a consequence of the corresponding innovation system performance. The systems perspective, in other words, is inward oriented and does not pay much attention to the system's environment. Consequently, external organizations that, for example, hinder the innovation process are treated as blocking mechanisms, although they may be much more than that, e.g. the result of strategic intervention of incumbent actors. Moreover, the systems approach runs the risk of missing influential processes because the review of the environment is less systematic. In a similar vein, novel technologies or products that emerge in competing innovation systems (and thus affect the innovation under study) may be neglected in the analysis (Markard and Truffer, 2008).

According to Malerba (2004), the sectoral innovation systems approach is centered on innovation in a specific sector, analyzing the system within the sectoral boundaries. It adopts a multidimensional, integrated and dynamic view of sectors in order to analyze innovation. It is based on the concept of *sector*, which is traditionally used in industrial economy studies and takes into account other agents that must be analyzed besides firms.

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Sectoral innovation systems approach emphasizes knowledge, learning processes and innovations. It also focuses on institutions, non-market and market interactions. According to Malerba (2004), in sectoral innovation system analysis, innovation is the central focus and can be affected by three sets of basic factors:

- *knowledge and technology*—particular knowledge base, technologies and inputs from the sector;
- *players and networks*—heterogeneous agents that can be organizations or individuals and their relationship networks and;
- *institutions*—cognition, actions and interactions of agents shaped by the institutions, which include norms, routines, customs, laws, etc.

The sectoral innovation systems approach has also been criticized due to sectoral boundary limitations, where some of the most important relationships could be missed because it is undertaken by actors outside a particular sectoral boundary. However, according to Niosi (2008), the study of specific sectors can be better understood when complemented by the inclusion of supporting organizations and technological regimes, as proposed by Breschi and Malerba (1997) and Malerba (2004). Niosi (2008) suggests this is particularly relevant for economic development, as the economic structures of most countries, industrial or developing, are composed of a few innovative sectors.

The technological innovation systems approach is centered on a specific technology, emphasizing a given technological field. It can be conceived as one or more networks of agents interacting within a specific technological area, under a particular institutional infrastructure with the purpose of generating, disseminating and using the technology. Technological systems are defined in terms of *knowledge flows* and *capabilities* rather than ordinary goods and service flows (Carlsson, 1995). Technological innovation systems are composed of dynamic knowledge and by technological capabilities networks (Carlsson and Stankiewicz, 1991). Carlsson (1995, p. 8) stresses that the technological innovation systems approach views the technology as knowledge, and conceptualizes technological development as a problem-solving process, with key elements such as: *technological infrastructure*, *knowledge networks and capabilities*, *critical mass and economic competence*, and *the role of public policies*.

A weakness of the technological innovation systems approach is its focus only on technological innovation and not other types of innovation. The OECD Oslo Manual (2005, p. 46), one of the most used manual for innovation issues, states that innovation is related to the "implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations". However, many studies provide conceptual and empirical evidence that supports the usefulness of the technological innovation systems approach for analyzing emerging technologies, and in particular sustainable innovations (Jacobsson and Johnson, 2000; Hekkert et al., 2007; Suurs and Hekkert, 2007). Due to the particularities of technologies studied here (oil well technologies) the technological innovation systems approach will be useful to address other important features of the agglomeration, as technological and scientific diversity must be considered as an indication of system performance, as it reflects the robustness of the system and its growth potential (Carlsson et al., 2002).

The technological innovation system approach presents some advantages and some disadvantages in relation to sectoral innovation system, depending on the perspective in which the system would be analyzed. The former focuses on a single technology related to several economic sectors, presenting a *cross-sector feature*, while the sectoral innovation systems approach focuses on a single sector which is related to several technologies, presenting a *cross-technology feature*. However, when used jointly, these approaches may complement each other, not considering spatial proximity as an obligatory feature but presenting the flexibility of being applied under any geographical stratification. Naturally, to some extent, they may overlap and, in a particular research area, the use of one or another approach must be chosen based on the objectives and perspectives of the study.

4. Multinational companies and global resource industries

Since many firms in this study are MNCs, it is important to conceptualize the term. Lipsey (2001) argues that a MNC consists of a parent firm and the affiliates it owns or controls. The parent firm is located in its home country (usually its world headquarter) and the affiliates are all the other plants and subsidiaries located elsewhere. Cantwell and Iammarino (2003) state that a large and growing share of innovation is concentrated in and around MNCs by virtue of their size, geographical locations and their ability of balancing the use of knowledge both intra-firm and extra-firm resources.

The global resource industries are generally known for the presence of large players rather than smaller firms, with substantial R&D investments to reduce costs and improve productivity. Finch and Acha (2008) suggest that the oil and gas industry is mature, encouraging firms to exchange oil fields in order to extend their production life, especially in the UK provinces. Matos and Hall (2007) found that a mature multinational was able to extend profitability by expanding their competencies in non-conventional oil sands in Alberta, Canada through technological innovation and by shifting competencies from those based on exploration to mining. Hall and Vredenburg (2003) found that Suncor Energy, a large Canadian oil sands operator, were able to exploit technological competencies through non-technological innovation. Harris and Khare (2002) argue that, after maturity, the future will likely favor companies that can best integrate growth with a low cost strategy and environmental protection, and that size will likely to be important because it correlates with access to financial resources and scale economies. However, it is not the case in immature oil & gas provinces, such as Brazil and other new provinces. In those areas, large R&D investments can be observed, specifically in contexts of deep and ultra-deep water E&P activities, as the Brazilian case. Corroborating with this argument, Woiceshyn and Daellenbach (2005) argue that in addition to uncertainty, the application of most technologies in the E&P oil & gas industry is unique to a particular site, rendering its outcomes highly unpredictable.

Archibugi et al. (1999) argue that multinational firms have a major and visible influence on national innovation systems. More specifically, Sharpe and Guilbaud (2005) indicate that MNCs are important in transferring technologies from their home country to other host countries, both through greenfield physical investments, implementation of more effective managerial practices and the transfer of best practice technologies. They suggest that a high degree of foreign direct investment in a particular industry may improve the industry's ability to innovate. Hewitt-Dundas et al. (2005) argue that MNCs are a potentially important channel through which world-class knowledge can flow into the country and stimulate innovation in other local businesses. In recent years, an increasing share of foreign direct investment by multinationals involved R&D activities and facilities (Carlsson and Mudambi, 2003). For this reason, Carlsson (2006) states that innovation systems may have become more spread over time, since the role

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of tacit knowledge and the spatial limits on knowledge spillovers have caused firms to locate R&D facilities where new knowledge is being created, rather than their particular home countries.

5. The theoretical framework and definitional constructs

The theoretical framework of this paper draws on elements from the clusters and from the sectoral and technological innovation systems approaches, in order to catch important features of the Campos Basin oil & gas province. The sectoral and technological patterns observed in the Campos Basin oil & gas province, together with the clusters approach form a powerful tool to analyze this industrial agglomeration of high technological complexity and sectoral dynamism.

Most studies take a broad perspective of a cluster, defined as a group of firms operating in one or more correlated sectors or complementary industries and spatially concentrated. Thus, special attention is given to *geographical proximity* of firms and *productive specialization* (Basant, 2002; Albu, 1997). Here, we use the broad definition for industrial clusters, as stated by Basant (2002): *a group of firms operating in one sector or complementary industries and spatially concentrated*. A working definition for geographical proximity means reduced transportation costs, easy accessibility for firms and individuals, shared cultural features and similar institutions (in the sense of norms, routines, customs, laws, etc.).

The relationship between clusters and innovation systems approaches has been widely discussed in the literature. For example, Cook and Memedovic (2003) conclude that clusters are specific sub-systems operating within regional innovation system settings. Langford and Hall (2007) argue that clusters must be recognized as an industry-specific idiosyncratic subgroup of a regional innovation system that achieves constructed advantages through evolutionary and path dependent innovation, while Mytelka and Farinelli (2000) not all clusters are innovation systems. In our view, the innovation system approach is composed of several clusters in different industries and sectors. It also can be related to one specific sector or a particular technology, but still able to observe different clusters. A local innovation system may be composed by a single cluster, or a group of cluster.

The concept of technological changes and innovation means that something new was applied by a particular firm. According to the OECD Oslo Manual (2005), technological change can be classified in three different ways: new to the firm, new to the market or new to the world. They define the market as (p. 58) "the firm and its competitors and it can include a geographic region or product line. The geographical scope of new to the market is thus subject to the firm's own view of its operating market and thus may include both domestic and international firms". In this paper, technological changes and innovations are classified as new to the Campos Basin oil & gas province.

In order to analyze the Campos Basin oil & gas province, it is necessary to carry out another important distinction between two concepts: *production system* and *knowledge system*. Bell and Albu (1999) define the production system as the projects of products, materials, machinery, labor, and market connections involved in the production of goods and services within certain specifications. The knowledge system is the stocks of knowledge within firms and flows of knowledge among and inside firms. The production system "encompasses those flows of knowledge, stocks of knowledge and organizational systems involved in generating and managing changes in the products, processes or organization of production" (Bell and Albu, 1999, p. 1723). They argue that the description of a firm, a cluster or a sector in terms of its production system does not provide sufficient information about the evolution of the firm or cluster under analysis, whereas the knowledge system can provide important insights about these features.

Knowledge linkages, which jointly form a knowledge system (that can also be strong or weak, depending on the case), can allow companies to develop networks and a series of stable relations based on trust that facilitate the access to new markets, both national and international (Bell and Albu, 1999). For the purpose of this study, knowledge linkages can be divided into two categories: *intra-agglomeration linkages* and *extra-agglomeration linkages*. Intra-agglomeration linkages can be critical for establishing relationships with other firms and organizations, allowing firms to develop tighter partnerships and knowledge-acquisition networks from which many of the new technological changes implemented in the agglomeration may arise. Linkages among geographically close organizations may yield better results in virtue of easier direct contact, discussion of new techniques, and development of informal and extra-company relationships. Particularly for the resource-based industries, the exact understanding of the operational conditions under firms work may be a factor that facilitates the interactions among actors, through their engineers, managers and others. This aspect is particularly important in oil & gas provinces, where the natural features and operational conditions are very peculiar (i.e. problems are better understood, discussed and solved among firms that operate under that given condition).

Extra-agglomeration linkages, on the other hand, may also have an essential role in the renewal and revitalization of the agglomeration concerning its knowledge base, allowing it to exchange knowledge with the external environment and preventing it from being technologically 'stuck' on internal knowledge flows. The effects of limiting external linkages could lead the agglomeration to lose the external (international) tendency (i.e. what other firms are doing in other provinces and in other parts of the world), regarding technological changes and innovations, which could generate a mismatching between these trajectories and the agglomeration's definitive technological deterioration in the long term (Bell and Albu, 1999).

The importance of extra-agglomeration linkages becomes evident "since the mere reliance on localized knowledge can result in the 'entropic death' of the cluster that remains locked-in to an increasingly obsolete technological trajectory" (Giuliani and Bell, 2005, p. 48). Malmberg (2003, p. 159) reinforces this idea, stressing that "interactions in local milieus are fascinating and interesting, but understanding global connections is at least equally important". Thus, well-established and stabilized knowledge linkages, both intra-agglomeration and extra-agglomeration, can be a channel for exchange experience, information and knowledge, as well as a locus for knowledge creation (Martin-de-Castro et al., 2008), allowing firms to acquire innovative technological capabilities and the capacity to adapt themselves to market pressures, targeting the long-term sustainability (Bell and Albu, 1999; Figueiredo, 2003; Batheld et al., 2004; Silvestre and Dalcol, 2007, 2008).

The traditional use of the clusters approach in the empirical literature is mostly concerned with manufacturing features and production systems, with linkages based on flows of goods and services (Schmitz and Nadvi, 1999; Bell and Albu, 1999; Giuliani et al., 2005a). Thus, with little emphasis on the evolution of the knowledge system, the role of technological changes and innovation, emphasizing mainly the production systems, the approach is insufficient to catch the target features of the agglomeration's dynamics (for critics, see for example Giuliani, 2004; Malmberg, 2003; Malmberg and Maskell, 2002). Based on this argument, the *global element* (no geographical boundaries defined) and the

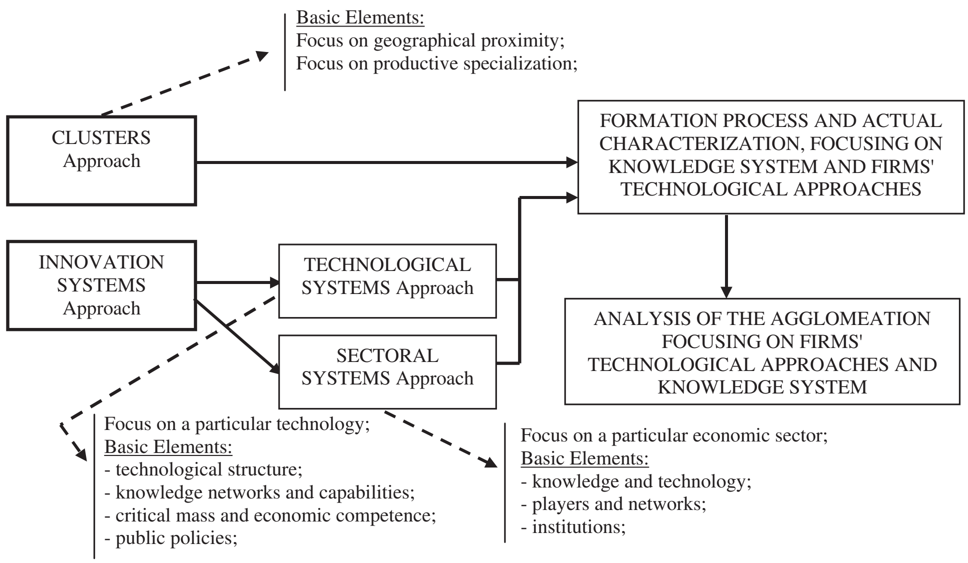

Fig. 1. Theoretical framework.

systemic element of the innovation system approach are added to this analysis. The term systemic introduces the *diversity of players* and *complexity of interactions* as two of the main characteristics. Diversity of players refers to the carefully analysis of firms *and* non-firm organizations such as universities, research institutes, regulatory bodies, public organizations, financing organizations, etc., that contribute to the development of the agglomeration's activities. Complexity of relations refers to an equal emphasis on intra-agglomeration linkages, as well as extra-agglomeration linkages between two organizations, without favoring the first, which is usually the focus of many clusters studies (Batista and Swann, 1998; Beaudry and Breschi, 2003; Malmberg, 2003). The term *technological dynamism* relates to the technological changes and transformations by which firms constantly adapt and modify themselves in the search for long-term sustainability (Freeman, 1988; Edquist, 1997; Johnson, 1997; Carlsson et al., 2002). Since the geographic area where the industrial agglomeration is located matters for the analysis (Saxenian, 1994; Herrera and Nieto, 2008), the economic sector in which it operates is also relevant. Thus, if the sector and the location are to be taken into account, differences among geographic areas and sectors may also represent important features to be highlighted in analyses (Pavitt, 1984).

For the purpose of this work, the term *technological capabilities* draws on Figueiredo's (2003) definition as the resources necessary for generating and managing technological changes like *abilities*, *knowledge and experience* and *organizational systems*. He states that different types of technological capabilities were first classified by Lall (1992) and successfully used by Bell and Pavitt (1995) that distinguished between *routine technological capabilities*, or the abilities needed to use technology, knowledge and organizational mechanisms, and *innovative technological capabilities* that consist of the abilities to creating, modifying or improving products and processes.

Due the limitation of the approaches presented in the literature as isolated tools, the analytical framework of this study uses elements from the clusters approach (Giuliani, 2004) and from the sectoral and technological innovation system approaches (Freeman, 1995; Malerba, 2004; Carlsson, 1995). Due to the need for collecting complex dimensions like territoriality, learning processes, technological capabilities, technological changes and innovations were also incorporated (Fig. 1).

6. Methodology

The methodology is divided into two distinct but related components: the *analytical method* and the *data collection method*. The analytical method describes the data analysis strategy based on the theoretical framework. Two key dimensions, derived from the theoretical framework, make up the analytical method of the empirical data: the *structure of knowledge linkages* (knowledge system) used to implement the technological changes and the *firms' technological approach*, described in the Section 6.1. The data collection method presents a specific strategy of analysis for innovations and technological changes applied to the selected firms in the empirical study, as described in Section 6.2.

6.1. Analytical method

From the proposed theoretical framework, two key dimensions were determined: the *structure of knowledge linkages* and the *firms' technological approach*. Knowledge linkages, which jointly form the knowledge system, can allow the firms to learn, acquire knowledge, absorb technological capabilities and tighten valuable relationships with other actors. A knowledge linkage can be classified into two categories: intra-agglomeration and extra-agglomeration linkages. An actor can be a firm or a non-firm organization (universities, research institutes, associations, government bodies, and others). Taking advantage of those linkages (i.e. stable relationships with other global players) may be essential for the long-term sustainability of firms, since the oil & gas provinces undergo a natural cycle: birth, growth, maturity and decline, at which point a new province emerges elsewhere. The life cycles of the oil & gas provinces around the world may of course overlap.

The studied agglomeration, the Campos Basin oil & gas province in the Rio de Janeiro State, is the largest producer of oil & gas in Brazil, with more than 85% of the country's total production. Thus, for this study, firms inside that State are geographically close and knowledge linkages inside that area are regarded as intra-agglomeration linkages, whereas linkages that cross the State's border are regarded as extra-agglomeration linkages.

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A linkage structure can be classified as *internally connected*, meaning that intra-agglomeration knowledge linkages can be observed with for example suppliers, buyers, competitors, research institutes, universities or associations. In this case, both actors are located inside the agglomeration. When those intra-agglomeration linkages are not verified in a given structure, this structure can be classified as *not internally connected*. Similarly, when a structure is classified as *externally connected or open*, this means that extra-agglomeration knowledge linkages can be observed with for example suppliers, buyers, competitors, research institutes, universities or associations. When those extra-agglomeration linkages are not verified in a given structure, the structure can be classified as *not externally connected or closed* (Table 1).

The second key dimension (Table 2) allows us to understand how the firms' technological approaches are regarding to the novelties implemented by technological changes. Following Athreye (2001), Baldwin and Hanel (2003) and Figueiredo (2003), firms may present four different types of technological approaches: (1) *mere user of the technology*, (2) *able to carry out minor adaptations in the technology*, (3) *able to carry out design changes in the technology*, and (4) *able to innovate*. The first approach is where firms simply use imported technology without any adaptations and know little about the technology, often referred to as a 'black box' approach. Specialized technical assistance is provided by third parties, and any changes in the technology are made with extra-company resources. In the second case, the company is able to carry out minor adaptations in technologies originating outside the firm, but external resources are needed to provide technical assistance. In the third approach, the firm is able to carry out design changes in technologies developed elsewhere, but some technical assistance is still required for items with higher technological content. In the last situation, the firm is completely proficient in that given technology and is able to innovate, making use of its accumulated knowledge-base. In this case, the technology can be radically changed using the firm's internal resources.

Besides these two key dimensions—knowledge linkage structure and firms' technological approach—the degree of intensity of each knowledge linkage observed in the empirical study was also analyzed (Table 3). This variable is important because presenting countless knowledge linkages would not be relevant if they were not qualified in terms of their intensity. For a firm, it may be preferable to have a few strong knowledge linkages than many weak knowledge linkages (Athreye, 2001; Baldwin and Hanel, 2003; Figueiredo, 2003, Holbrook and Wolfe, 2005).

Fig. 2 shows the confrontation between the agglomeration's knowledge structure and the firms' technological approaches. Events located in row A present both intra-agglomeration and extra-agglomeration linkages. Row B represents structures in which only intra-agglomeration linkages exist. Row C represents structures in which only extra-agglomeration linkages exist. Finally, row D represents events with no connections. Regarding the columns, column 1 represents events in which the actor is merely a user of the technology; in column 2, the firm is able to carry out minor adaptations; in column 3, the firm is able to carry out design changes in the technology used; and in column 4, the firm is able to innovate. The shaded cells represented by quadrants A3, A4, B3 and B4, are the positions representing the influence of the agglomeration (as they are internally connected), thus contributing to an approach more directed to the development

Table 1
Structure of knowledge linkages.

Structure of linkages	Externally	
	Connected (or opened)	Not connected (or closed)
Internally		
Connected	Linkages structure connected with actors located inside the agglomeration and also connected with actors outside the agglomeration (opened structure)	Linkages structure connected with actors located inside the agglomeration but not connected with actors outside the agglomeration (closed structure)
Not connected	Linkages structure not connected with actors located inside the agglomeration but connected with actors outside the agglomeration (opened structure)	Linkages structure not connected with actors located inside the agglomeration and neither with actors outside the agglomeration (closed structure)

Table 3
Degree of intensity of the knowledge linkages.

Degree of intensity	Characteristics
Strong	Knowledge linkage related to the establishment of formal R&D agreements. The establishment of this type of linkage evidences the firm's active approach and a deliberate effort to be proficient in that given technology. Knowledge and technological capabilities acquisition are intense
Moderate	Knowledge linkage related to technician and engineer training initiatives, incorporating technological capacities to the firm's knowledge base. The establishment of this type of linkage evidences the firm's tendency to an active rather than passive approach. Knowledge and technological capabilities acquisition are moderate
Weak	Knowledge linkage related to the acquisition of specialized technical consultancy, national or foreign. The establishment of this type of linkage evidences the firm's tendency to a passive rather than active approach. Knowledge and technological capabilities acquisition are low
Very weak	Knowledge linkage related to the informal exchange of technological information and knowledge. The establishment of this type of linkage evidences a passive approach, without the firm's deliberate effort to incorporate this knowledge systematically. Knowledge and technological capabilities acquisition are very low

Table 2
Firms' technological approaches.

Firms' technological approaches	Mere user of the technology	Able to carry out minor adaptations	Able to carry out design changes	Able to innovate
Characteristics	Only uses a technology developed elsewhere. May not have interest or ability to develop innovative technological capabilities to carry out any adaptations in that given technology	Is able to carry out only minor adaptations. May not have interest or ability to developing required innovative technological capabilities to be able to carry out design adaptations	Is able to carry out design (major) changes in the technology. May not have interest or ability to developing required innovative technological capabilities to be able to innovate radically	Is able to carry out even radical changes and innovations, presenting a complete set of innovative technological capabilities related to that given technology

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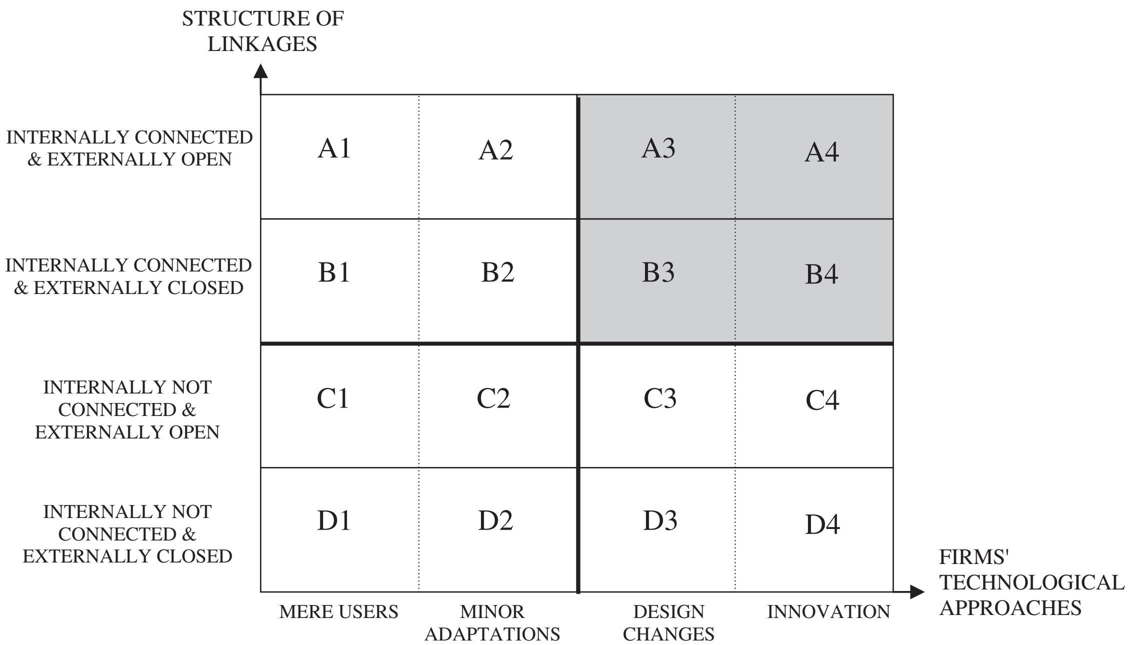

Fig. 2. Knowledge linkage structure and firms' technological approaches.

and utilization of innovative technological capabilities (i.e. firms are able to carry out design changes and innovations in a particular technology). Based on this analytical method, it is possible to formulate some important considerations about aspects such as geographical proximity and innovation.

6.2. Data collection method

The research method adopted was the case study because this type of approach is useful to investigate contemporary phenomena within a real-life context, especially when the boundaries between the phenomenon and the context are not clearly evident (Yin, 2003). Under this method, 10 case studies were conducted in firms operating in areas of intense technological dynamism and located in the Campos Basin oil & gas agglomeration, meeting Eisenhardt's (1989) suggestions regarding data saturation. Two groups of suppliers located in the Campos Basin agglomeration and operating in the oil & gas industry were studied. The first group is composed of firms that provide well technology services (installation, maintenance and repair of wellhead systems and well structures, besides other well technology solutions). The second group is composed of firms that provide wellhead equipment, specifically 'wet christmas trees', a technology based on a series of connectors and valves used for subsea oil & gas production. Developed endogenously and currently unique to the Brazilian oil & gas industry, the installation of this equipment does not require divers.[1] Both groups are known for their high technological content in their goods and services. Apart from those two groups of firms, Petrobras, the highly influential national oilfield operator, was also an important subject of the empirical research.

The data was collected from primary and secondary data sources. The main data collection technique was interviews with key informants, selected among those in direct contact with the technology. Interviews were conducted with technology directors, base managers, technology managers or experienced engineers. Other information to this study was collected through unstructured conversations with other firms' employees and through direct observation during the site visits. Secondary data was acquired through researching the companies' annual reports, publications of support organizations (associations, unions and other organizations), newspapers and specialized technical journals.

Firms analyzed in this study were chosen from ONIP's suppliers' database (*Organização Nacional da Indústria de Petróleo*, or in English: National Organization of the Petroleum Industry). The ONIP's database is composed of all firms that operate in oil & gas industry in Brazil, both national and international. The choice of firms was determined by the common characteristics that they should be suppliers of goods and services with significant technological complexity and in areas of relevant technological dynamism. This choice was based on characteristics of that agglomeration and on the information gathered from IBP (*Instituto Brasileiro de Petróleo*, or in English: Brazilian Oil Institute), RedePetro BC (network of firms that operate in the Campos Basin oil & gas agglomeration), Petrobras and ONIP. With this strategy, the focus was directed on firms in which technology represents a relevant factor in the goods and services provided.

Although the agglomeration has around 1500 firms operating in several areas, the sample used in this study is composed of all wellhead equipment suppliers in Brazil (only 4 supplying firms are able to provide this type of equipment and all of them were involved on the empirical study: Cooper Cameron, VetcoGray, Aker Kvaerner and FMC Technologies). For well technology suppliers, five supplying firms in the agglomeration are able to provide highly complex well technology services, all of which were involved in the study (Baker Hughes, Halliburton, BJ Services, Schlumberger and Weatherford). Petrobras, the dominant and most technologically dynamic oilfield operator in Brazil, was also included in the study, for a total of 10 firms.

The data collection unit consisted of *technological changes* implemented by the firms in the industrial agglomeration, named *events*. During the interviews, the focus was directed at specific events (technological changes implemented) rather than to the firms as a whole, as per the methodology used by Athreye (2001)

[1] Divers are highly trained professionals that encounter considerable risks and physical challenges when operating in deep waters. Conditions are so difficult that they usually retire within 15 years of work.

and Baldwin and Hanel (2003). The events were identified by the interviewees themselves (key informants), and therefore represent key technological changes implemented in recent years by that firm in the agglomeration. The relevance of these events was verified with other managers of those firms, with their competitors, suppliers and with Petrobras in subsequent interviews carried out for this purpose. Such a strategy helped attenuate some potential problems identified before the empirical work, namely the small number of firms in each chosen group and the risk of losing of focus during the interviews. Thus, by increasing the number of analyzed events and directing the interviews toward only a single event, the precision of the answers and the results was improved. A total of 25 valid events were determined, as each company identified between 1 and 4 events (2.5 events per firm on average). In the 25 events studied, 75 knowledge linkages were identified so that those technological changes could be implemented in the agglomeration, as each event observed presented between 1 and 5 knowledge linkages each (3 linkages per event on average).

7. Formation process and characterization of the industrial agglomeration

The formation process of the Campos Basin oil & gas industrial agglomeration emerged gradually, accompanying the discoveries of oilfields and with Petrobras as the leader for its emergence and subsequent development. The first oilfield, *Garoupa,* was discovered in 1974, and Petrobras set up units in the area to provide infrastructure as well as technical and engineering support. This was a gradual process, intensified with the economic feasibility due to a relatively constant discovery of new fields. This region emerged as an important point of interest for firms of all types, operating directly or indirectly in the oil & gas industry.

Direct suppliers soon followed Petrobras to the region, the first being suppliers of goods and services with high technological complexity and long-term contracts with the Brazilian oilfield operator. Numerous other firms later migrated from various Brazilian regions and from abroad attracted by the presence of Petrobras as well as the presence of other large international suppliers. Other firms emerged through entrepreneurial initiatives and from knowledge spillovers, usually operating in niche markets. The role of Petrobras in the formation process of the industrial agglomeration was thus crucial, and this role continues due to the still limited presence of foreign oilfield operators, due in large part to restrictions imposed by the Brazilian Federal Government. Although the presence of MNCs increased over the last few years, mostly through joint ventures. Petrobras remains the most important player and the most desired partner for any oilfield operator in the Brazilian oil & gas upstream segment. In addition to government protection, Petrobras also possesses accumulated knowledge acquired over the last 30 years, providing the firm with substantial competitive advantage within this specialized area.

The configuration resulting from this agglomerating process is an extensive supply network with several technologically complex levels and degrees of responsibility of each firm (Fig. 3). It can also be observed that there is a clear stratification within the agglomeration in terms of technology. In this regard, we can point out four different groups of firms present in the agglomeration: (1) *operators of oil & gas fields*, (2) *suppliers of offshore goods and services of high technological complexity*, (3) *suppliers of offshore goods and services of moderate technological complexity*, and (4) *suppliers of goods and services of low technological complexity*. A fifth group is composed of non-firm organizations (or *support organizations*) and is also located in the Campos Basin oil & gas industrial agglomeration (Fig. 3).

In the first group, there are 11 operators of oil & gas fields: Petrobras (the major participant), Total Fina Elf, Shell, Exxon Mobil, Repsol-YPF, Wintershull, Devon, ChevronTexaco, Agip, Unocal and Ocean Energy INC. Of the 10 foreign oilfield operators, 9 have E&P projects with Petrobras (Silva, 2004). These companies are technologically dynamic and require intensive and constant R&D.

The second group consists of around 50 suppliers of offshore goods and services of high technological complexity, operating in

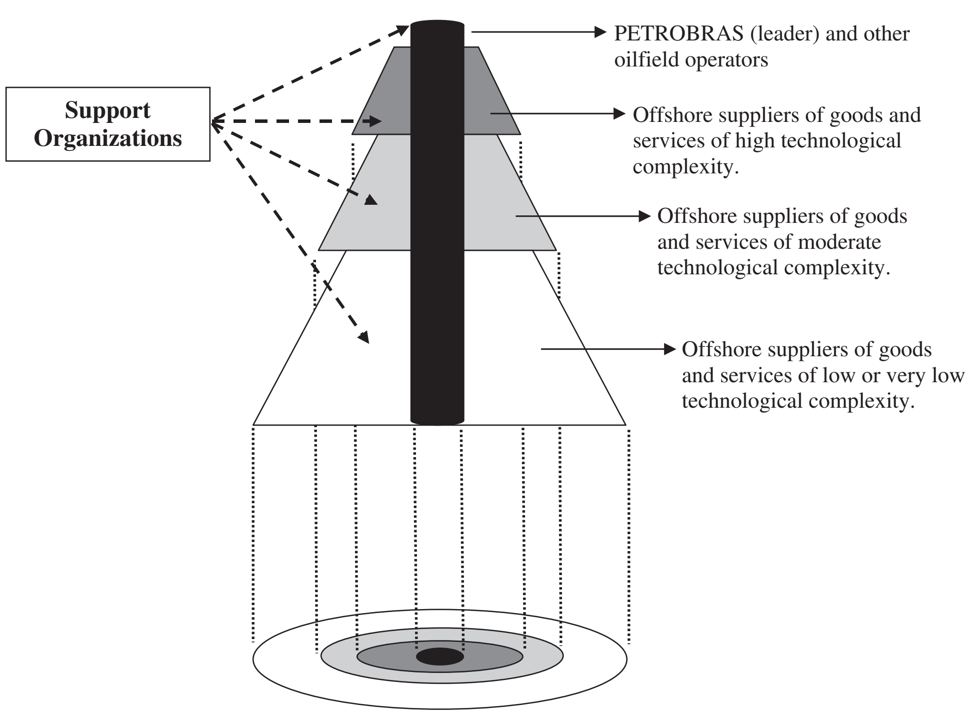

Fig. 3. Actual characterization of the Campos Basin oil & gas industrial agglomeration.

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Table 4
Non-firm organizations that support the Campos Basin oil and gas industrial agglomeration.

Support organizations	Name	Role and characteristics	Web-page
ANP	National Agency for Petroleum, Natural Gas & Biofuels	Regulatory agency affiliated to the Ministry of Mines & Energy	http://www.anp.org.br/
CENPES	Petrobras' Research Centre	Used to develop the major technology developments of the Campos Basin province	http://www2.petrobras.com.br/portal/tecnologia.htm
SEBRAE	Brazilian Service for Supporting SMEs	Organization with regional offices in Campos, Macaé, Niterói and Rio de Janeiro, offering services related to micro-credit, technical and management training, interactions facilitators, projects analysis and follow-up and others	http://www.sebrae.com.br/
FIRJAN	Rio de Janeiro State Federation of Industries		http://www.finjan.com.br/
CREA-RJ	Engineering and Architecture Council of Rio de Janeiro		http://www.crea-rj.org.br/
SENAI	National Service for Industrial Learning		http://www.senai.br/
ONIP	National Organization for the Petroleum Industry	Networks of firms that operate in the Campos Basin oil & gas industrial agglomeration, providing several different types of support services (burocratic, technical and management training, interactions facilitator, sector information, R&D, periodic meetings among the province's actors and others)	http://www.onip.org.br/
IBP	The Brazilian Oil Institute		http://www.ibp.org.br/
REDE-PETRO BC	The Network of Oil Firms of the Campos Basin		http://www.redepetro-bc.com.br/
REDE-TEC	Rio de Janeiro's Technology Network		http://www.redetec.org.br/
PROMINP	National Oil Industry's Mobilization Program		www.prominp.com.br
ASSESPRO	Brazilian Association of the Information Technology Firms		http://www.assespro-rj.org.br/
PUC-Rio	Pontifical Catholic University of Rio de Janeiro	The country's top private university, according to the Brazilian Ministry of Education (MEC)	http://www.puc-rio.br/
UFRJ	Federal University of Rio de Janeiro	Four federal universities located in the Rio de Janeiro State and two of them being ranked among the best Universities in the Country (UFRJ and UFF), according to the Brazilian Ministry of Education (MEC).	http://www.ufrj.br/
UFF	Fluminenses Federal University		http://www.uff.br/
UFRRJ	Federal Rural University of Rio de Janeiro		http://www.ufrrj.br/
UNI-Rio	Federal University of the Rio de Janeiro State		http://www.unirio.br/
UENF	State University of Norte Fluminense	Two state Universities and one of them are being ranked among the best universities in the country (UERJ), according to the Brazilian Ministry of Education (MEC).	http://www.uenf.br/
UERJ	State University of Rio de Janeiro		http://www.uerj.br/

More than 20 private educational organizations (universities and colleges).
Several Commercial Associations, Municipal and State's supporting organizations (public organizations).

areas of intense technological dynamism, having large bargaining power with the buyers (all oilfield operators). Most of these companies are multinationals and without their presence in the Campos Basin, Petrobras probably could not develop E&P projects (Silvestre, 2006). The focus of the present work is on this second group, which can be further divided into the following subgroups:

- prospecting services (surface geological services, aerial photogrammetry, magnetometry, gravimetry and seismic studies, conducted in modern exploration ships and data analysis tools to helping detection of oil & gas fields in the ocean, with 3D and 4D technology);
- drilling services (drilling column services and drilling operations);
- suppliers of wellhead equipments (wet christmas trees, manifolds, equipments for pumping oil & gas, well-safety and accident-prevention equipments and systems, etc.);
- suppliers of well technology services (well technology solutions like completion and cementing of wells, well profiling, pressure tests, fluid technology, conditioning and stimulation of wells, pumping systems, etc.);
- other offshore services and equipment (services and equipment related to ROVs—remotely operated vehicles—and other offshore goods and services characterized by high technological content).

The third group is composed of firms that supply goods and services for offshore activities but without major technological complexity and dynamism. This includes general safety equipment and services suppliers, preventive maintenance and repairs of electrical equipment and systems firms, diving services firms, suppliers of boiler and welding services, maritime transportation and air transportation services. The fourth group includes suppliers of ancillary goods and services that are not within the customers' strategic areas, such as cleaning and maintenance, catering services, lodging, security, offices' materials insurance, etc. There is also a large and important network of non-firm and research organizations supporting E&P activities and firms in the Campos Basin agglomeration, as shown in Table 4.

8. Empirical results

Table 5 summarizes the 25 valid events (technological changes) from the 10 case studies. Examples worth highlighting include *horizontal coated multi-fractured equipment* that brought substantial benefits in oil well stimulation and a better utilization of the oil, optimizing the well production; the development of *multiplex control systems*, which allowed electronic control of valves located at depths of 3000 m, a major technological endeavor, given the particular temperature of the water, tidal conditions and specially the pressure on the equipment; and the *acoustic control systems*, which eliminated the use of umbilical cables that connect the floating structure to the submersed equipment.

As shown in Fig. 4, out of the 25 technological events analyzed, 11 (or 44%—plotted in the shaded cells) show evidence that

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Table 5
Valid events and linkages per firm.

Groups	Firm	Events	Total events/groups	Linkages	Total linkages/groups
Wellhead equipment suppliers (wet christmas tree)	Cooper cameron	2	9	7	31
	VetcoGray	3		9	
	Aker Kvaener	1		4	
	FMC technologies	3		11	
Well services suppliers (well technology)	Baker Hughes	2	12	4	28
	BJ Services	2		5	
	Schlumberger	2		4	
	Weatherford	3		9	
	Halliburton	3		6	
Main operator	Petrobras	4	4	16	16
Total	10		25		75

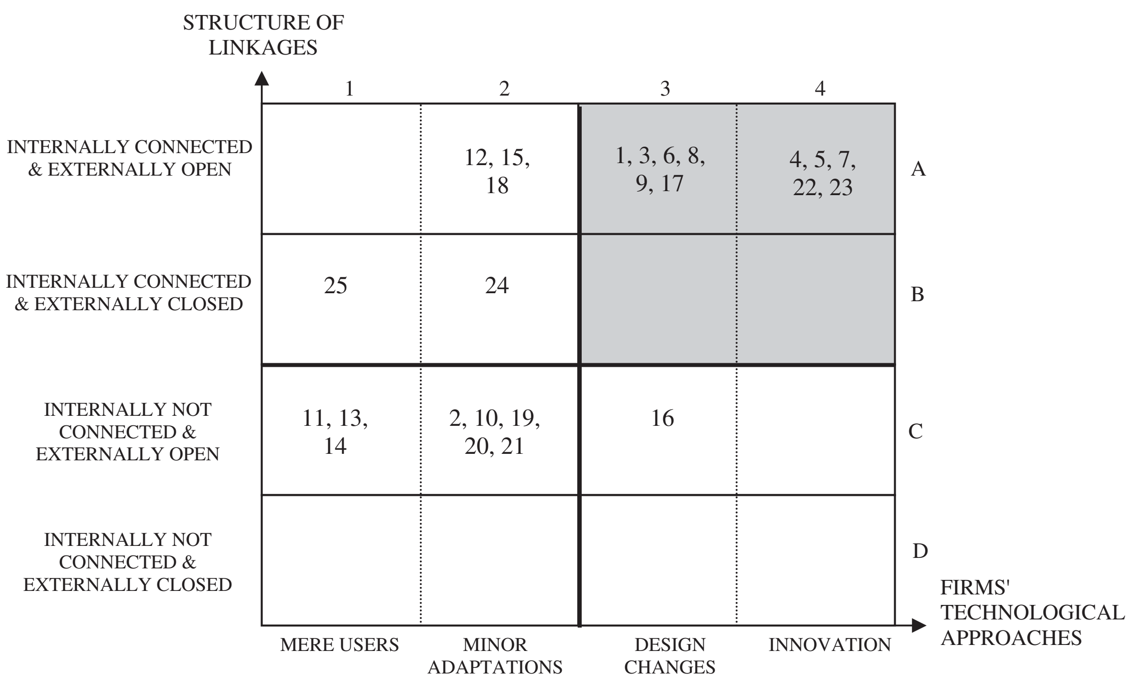

Fig. 4. Plotting of events—knowledge linkages structure and firms' technological approaches.

technological proficiency which leads to innovation is positively influenced by firms that are agglomerated in the same geographical space, i.e. they are physically close to one another and interacting intensely with each other. On the other extreme, 56% of the events do not present any evidence that this influence takes place, because the structures have no linkages whatsoever with players located inside the agglomeration (intra-agglomeration linkages) or because their technological proficiency is restricted.

In relation to the horizontal axis, out of the 25 events, 4 (16%) show that firms are mere users of that given technology (column 1 in Fig. 4) and have no technological proficiency in the area. In these events (11, 13, 14 and 25), firms are either unable to change the technology or have no interest in doing so. In the first case, firms do not have means to control the technology due to their lacking absorptive capacity to accumulate technological capabilities. In the second case, the firms prefer to hire a third party to provide this technology and are not concerned about absorbing that particular technological knowledge because it is not in their area of interest. In some cases, the technology can originate in the company's affiliates or headquarters outside the agglomeration. Regarding this situation, the company's operational base in the Campos Basin industrial agglomeration may not have the technological capabilities required for the innovations for political reasons (there is no interest in investing in innovative technological capabilities inside the province). Thus, technology is developed outside the agglomeration where the company maintains its R&D centers, while the operational base of the company located in the province is an agent for task execution (a mere implementer of technologies generated elsewhere).

Out of the 25 events analyzed in the empirical study, 9 (36%) show that firms are able to carry out only minor adaptations in that given technology related to a given event (column 2 in Fig. 4). In these events (2, 10, 12, 15, 18, 19, 20, 21 and 24), firms are able to adapt the technology only superficially or have little interest in doing so.

From the total number of events analyzed in the empirical study, 7 (28%) show that firms are able to carry out design changes in that given technology (column 3 in Fig. 4). In these events

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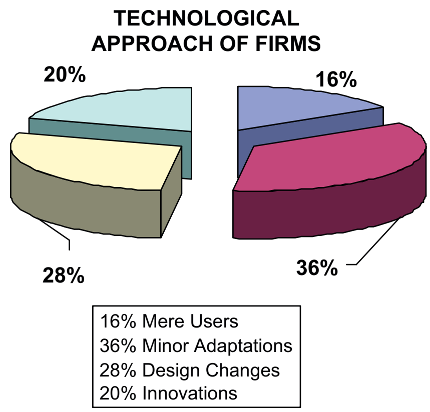

Graph 1. Firms' technological approaches.

Table 6
Knowledge linkages' intensities.

Level of intensity	Strong	Moderate	Weak	Very weak	Total
Wellhead equipments	25	0	5	11	41
Well services	8	7	19	0	34
Total	33	7	24	11	75

Table 7
Intra-agglomeration linkages and technological capabilities used.

	Routine technological capabilities	Innovative technological capabilities
Internally connected	5	**11**
Internally not connected	8	1

Table 8
Intra-agglomeration linkages and technological capabilities used (wellhead equipments suppliers).

	Routine technological capabilities	Innovative technological capabilities
Internally connected	0	8
Internally not connected	1	0

(1, 3, 6, 8, 9, 16 and 17), firms are able to change the technology extensively. Firms have considerable technological proficiency and may be investing even more to increase the technological knowledge (see the horizontal axis in Fig. 4). Five (20%) of the events show that firms are able to innovate in that given technology (column 4 in Fig. 4) and have a thorough proficiency over the technology related to a given event. In these events (4, 5, 7, 22 and 23), firms are able to change the technology even radically, promoting innovations. They have implemented technological changes based on innovations developed inside the company. The consolidation of the information related to the firms' technological approach is presented in Graph 1.

In relation to the vertical axis, which establishes the characteristics of the knowledge linkages structure, out of 25 events, 14 (56%) were found to have an internally and externally connected structure (row A). In these events (1, 3, 4, 5, 6, 7, 8, 9, 12, 15, 17, 18, 22 and 23), the interactions between the firms and other actors located inside and outside the industrial agglomeration are observed. Similarly, 2 out of the 25 events (8%) show a knowledge linkages structure internally connected and externally not connected (closed to the external environment—row B). In these events (24 and 25), there are connections between the studied firms and other firms and/or non-firms organizations located inside the agglomeration, but no connection with actors located outside the industrial agglomeration. Related to the row C, 9 events (36%) show a knowledge linkages structure internally not connected and externally connected (opened to the external environment). In these events (2, 10, 11, 13, 14, 16, 19, 20 and 21), it is possible to observe the relationships of the studied firms with firms and non-firm organizations located outside the agglomeration, but without any connection with actors located inside the industrial agglomeration. None of the events studied showed absence of knowledge linkages, i.e., a structure not connected neither internally nor externally. For that reason, no events were plotted in row D.

Analysis of the knowledge linkages intensities show the same trend displayed by the knowledge linkages structures. Well technology services suppliers showed a tendency to establish linkages of strong and moderate intensities in the same proportion as weak and very weak intensities. However, the extra-agglomeration linkages (global pipelines) have significant predominance over intra-agglomeration ones (local buzz). Suppliers of wellhead equipment showed a larger number of linkages of strong and moderate intensities (which indicates a more *active* approach in relation to technology capabilities absorption) (Table 6). Half of them were established with players located inside the industrial agglomeration, emphasizing the importance of geographical proximity for firms' innovative activities in this group.

For some firms, intra-agglomeration linkages favor a more innovative approach and the use of innovative technological capabilities (Table 7), consistent with Takeda et al. (2008). Regarding the shaded area (Fig. 4), 11 events plotted show an internally connected structure and the use of innovative technological capabilities. Of these 11 events, 8 are related to wellhead equipment suppliers, 2 related to Petrobras and only 1 related to the well services suppliers. Extra-agglomeration knowledge linkages are found in 92% of all events. This situation can be partly explained by the notion that those groups of firms are composed of many global players and multinational subsidiaries with stable relationships with actors from abroad.

According to the quadrant highlighted in the Table 7, in some cases the intra-agglomeration linkages favor a more innovative approach, allowing firms to carry out design changes and innovation in the technology (see the number in bold), represented by the events 1, 3, 4, 5, 6, 7, 8, 9, 17, 22 and 23. The industrial agglomeration may thus be contributing positively towards technological change and innovative capabilities. On the other hand, firms that have few or no strong intra-agglomeration linkages and are mere users of that technology, represented by the events 12, 15, 18, 24 and 25, show indications that the industrial agglomeration may not be contributing effectively for technological change and innovation.

Of the 9 events studied among the wellhead equipment suppliers, 8 (89%) show at least one intra-agglomeration knowledge linkage (Table 8). This situation shows that intra-agglomeration linkages are established consistently and are important for this group of firms. These firms have developed innovative technological capabilities, which give them technological proficiency that can consequently be able to carry out design changes and innovations (according to the bold numbers on Table 8). Of the 12 events studied among the well technology services

Table 9
Intra-agglomeration linkages & technological capabilities used (well technology services suppliers).

	Routine technological capabilities	Innovative technological capabilities
Internally connected	3	**1**
Internally not connected	7	1

suppliers, only 4 (33%) present intra-agglomeration knowledge linkages (Table 9) and in only one the use of innovative technological capabilities was observed (according to the bold number on Table 9). Intra-agglomeration linkages are less important for this group of firms, and mostly routine technological capabilities were identified. These firms had only low proficiency in the technologies, since they are usually mere users of the technology and sometimes they are able make minor adaptations, but unable to change the technology significantly. The events related to Petrobras (total of 4) were not considered in Tables 8 and 9, since the aim here is to understand the picture for the groups of suppliers separately.

Most events related to the wellhead equipments suppliers are plotted in the area where the geographical proximity seems to present a large influence on the behavior of firms (shaded area—Table 8). In that area, intra-agglomeration linkages were observed and the firms' technological approaches demonstrate a deliberate effort to absorb the knowledge and technology used. Those events illustrate the use of innovative technological capabilities by firms and a significant level of technological proficiency. The firms are able to carry out design changes and innovations in the related technology, providing evidence that geographical proximity is facilitating the innovative activities of those firms.

These results suggest that the suppliers of wellhead equipment have benefiting from being geographically clustered in the Campos Basin oil & gas industrial agglomeration in terms of innovation, since they are consistently establishing intra-agglomeration linkages and using innovative technological capabilities. The importance of tacit knowledge for these firms related to the productive and operational features of the Campos Basin province encourage them to stay close, allowing them to develop innovative technological capabilities jointly. Thus, for wellhead equipment suppliers, proximity matters. In contrast, suppliers of well technology services do not show evidence of benefiting, in terms of innovation, by being clustered in the Campos Basin agglomeration, since they draw on intra-agglomeration linkages sporadically and are also applying a less innovative approach (using most of times only routine technological capabilities). Petrobras' approach seems to be more *active* for the wellhead equipment area (in the coordination role for technology development) than for well technology service activities.

9. Implications and conclusions

This study attempted to improve our understanding of the relationship between knowledge linkages and firms' technological approaches in the oil & gas industry of Brazil, a country that until 1974 had almost no capabilities in this area. Since that time, Brazil has emerged as one of the leading centers for offshore production of oil & gas in deep and ultra-deep waters, contributing towards national energy self-sufficiency. Brazil differs from other resource-rich emerging economies, as they were able to accumulate local technological competencies specific to their resource-base industries.

The factors leading to this success are obviously complex, and the findings presented here are limited to those groups of firms that present a high technological dynamism in the supply of complex goods and services. Bearing these limitations in mind, we suggest that technological capability accumulation was facilitated by industrial agglomeration dynamics, specifically for the development and implementation of technological changes needed to overcome the natural challenges faced in oil & gas extraction in deep and ultra-deep waters.

The theoretical framework brings out the two key dimensions that form the analytical method used in the empirical study. The first is derived from the clusters approach: knowledge linkages among firms in a relatively small geographic area (knowledge system), represented in the vertical axis. The second key dimension is derived from the innovation systems approach: the firms' technological approach that brings out the sectoral and technological patterns of those groups of firms studied, represented in the horizontal axis (Fig. 4).

The empirical study shows that the current configuration of the Campos Basin oil & gas industrial agglomeration is a large network of firms led by Petrobras. Other oilfield operators have been developing their own networks to provide the goods and services needed to undertake E&P activities. The actual characterization of the Campos Basin agglomeration, regarding technological dynamism and complexity of the goods and services, was established based on the stratification of four different groups of firms (excluding support organizations). This strategy was adopted due to the actors' heterogeneity and the difficulties of applying a framework of analysis for the whole agglomeration, as the actors are quite diverse technologically. Viewing the industrial agglomeration as a technologically homogeneous object of study can be a crucial error, because generalizations made for the entire industrial agglomeration could result in inconsistencies and distortions.

Despite the presence of other oilfield operators in the province, Petrobras still plays the central role in the Campos Basin industrial agglomeration, both in its governance and in the percentage of orders made there. This configuration provides the agglomeration a highly vertical structure composed of several layers of suppliers, which have different levels of technological complexity in their goods and services and degrees of responsibility.

Generally, the knowledge linkages structure is *very open*, with the presence of many knowledge linkages established with actors located outside the agglomeration. In the well technology service supplier group, the linkages are observed in all 12 events analyzed. Most of those linkages were established with other divisions of the same firm, with its headquarters or the firm's research centers located in North America or Europe. This configuration, combined with the finding that the intensity of the linkages are not usually strong (see Tables 6 and 9) and the firms' technology approaches were observed as being *mere users* or *able to carry out minor adaptations*, indicates that in most cases those firms simply execute tasks inside the industrial agglomeration, using mainly *routine technological capabilities*. The group of wellhead equipment suppliers also displays a vast mesh of extra-agglomeration knowledge linkages, but intra-agglomeration linkages are much more intense than in the previous group (see Tables 6 and 8), indicating that they are taking advantage of being geographically clustered.

Here it is possible to argue that the technological changes implemented in the Campos Basin by the wellhead equipment suppliers originated in part from local interactions among actors within the agglomeration, with the dominant presence of Petrobras and its R&D and technological policies. There is a clear dominance of intra-agglomeration linkages, in the Petrobras events, most of them showing strong and moderate intensities.

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On the other hand, the technological changes in the well technology service activities predominantly originated from global connections. Most of these global connections supply Petrobras' demands for knowledge and technological capabilities, given their central position in the agglomeration (see benefits of connected position in Caloghirou et al., 2004), and presenting a strong technological absorptive capacity.

9.1. Implications for research

Apart from the geographical proximity and productive specialization (elements derived from the clusters approach), the theoretical framework also draws on elements from the innovation systems approach, specifically sectoral and technological perspectives. The innovation systems approach were added in order to catch some sectoral and technological patterns, some important elements to analyze the Campos Basin agglomeration centered on features such as knowledge system, technological capabilities absorption (organizational learning process and knowledge acquisition), and the implementation of technological changes and innovations, specially for the groups of firms studied. We used the sectoral innovation systems approach for focusing on *players and networks*. These networks can be related to production or knowledge linkages and this feature fits in this analysis, rather than an analysis centered only in the production networks as is the case for many other clusters studies. *Institutions* were also analyzed from the sectoral innovation systems perspective, since they are one of the main targets of those studies and the sectoral institutions are much clearer to observe in the localized agglomeration than any other perspective. From the technological innovation systems, we caught some basic elements such as, the *technological infrastructure*, shaped by those actors that hold the technological knowledge, such as the groups of firms studied, universities and other support organizations that participate on the development of those particular technologies. Again, the attention to *technological capabilities* and the *public policies* are also targets that derived from technological innovation systems studies, since they represent some of the key elements of its analysis, and are much better understood from the technological perspective.

Applying multiple perspectives provides a more robust approach for innovation and agglomeration studies and a bigger awareness of how multiple theoretical tools work jointly to carry out holistic analysis, even more when dealing with complex issues regarding to knowledge, inter-firm relationships, learning, technology and innovation. This strategy, of using a multi-theoretical approach, helps to illustrate a more accurate picture of the reality, using the strengths of existent theories by recombining them, rather than try inventing additional ones. Future research could enhancement and extension of the analytical method composed of the two key dimensions (knowledge systems and firms' technological approaches). The application of this theoretical framework to other oil & gas provinces, as well as to agglomerations from other economic sectors such as electricity, energy in general, automobile industry, aerospace industry, among others, would also be a relevant line of research.

9.2. Implications for policy

The multinationals' role and their interactions in developing countries are important features since they present sources of technological knowledge for many developing countries (Archibugi et al., 1999; Cantwell and Iammarino, 2003). However, in the case of Brazilian oil & gas, there was a strong necessity for a particular policies and a specific governance strategy in order to facilitate technology transfer and attract R&D activities in industry, rather than only production activities.

For more than 30 years policy makers have been developing the strategy and adjusting policies for the oil & gas industry in order to achieve a specific position in deep and ultra-deep waters production. This paper explored how this trajectory happened, recognizing the role of Petrobras in the establishment of the Brazilian industry, its technological development, capabilities accumulation and its internalization trend. This trend is not an easy path for a firm from an emerging economy and no other national oil & gas company has been able to create globally leading deep and ultra-deep well technologies, although a few have established an internationally competitive trajectory based on other type of technologies (Carvalho and Goldstein, 2008; Ahmad and Hashim, 2007). Petrobras can thus be a useful example for other national oil companies attempting to develop their resource-base while simultaneously developing national technological development.

Under Petrobras' leadership, the Campos Basin industrial agglomeration evolved into a large supplier network structure presenting different levels of technological complexity in their goods and services and degrees of responsibility. Given that it is a resource-based agglomeration, firms are there to exploit such resources and when those resources finish, it is likely that the cluster may dissipate as firms relocate to areas with new discoveries (in Brazil or abroad). Assuming that oil & gas provinces and, as a consequence, other dynamic industrial agglomerations such as Houston in the US; Aberdeen in the UK and Oslo/Stavanger in Norway have limited life spans due to the finite nature of oil & gas reserves, there is a likelihood that these provinces will see their activities slow down. In general, the life span of these provinces has four distinct stages: birth, growth, maturity and decline. In the decline stage, oil & gas production starts to decrease, forcing the firms located in the industrial agglomeration to migrate to more promising provinces elsewhere. The other alternatives are remain in the province but operate in another industries (migrate to a correlated industry, for example) or even die. In this context, policy makers need to be aware about the necessity for identifying alternatives for those local firms to survive and two different policies are suggested here, according to the technological complexity of firms. First, in order to help local knowledge-based firms enter the global oil & gas industry, it is necessary to proximate those firms closer to suppliers of goods and services of high technological complexity and also experienced multinationals, thus stimulating close relationships between them. This partnership can be the initial stimulus for the absorption of new innovative technological capabilities by local knowledge-based firms and the way for the sustainability in the long run. This process might create, in the long term, conditions for those local firms to become competent global suppliers in the oil industry, or even competitors of large multinational corporations located in Brazil and in other provinces around the world. This policy aims to encourage these firms to remain in the Campos Basin province and still play a role in deep water E&P elsewhere, taking advantage of the knowledge created and accumulated in the province.

The maintenance and attraction of R&D-related activities is also important to create the necessary environment for deepen the knowledge specialization in deep and ultra-deep waters E&P, to use the existent skilled labor force, becoming a high technological center for these type of technologies (like the Houston-based firms that still play an important role in the oil industry knowledge creation and technological development). Second, the necessity for a policy directed to local non-knowledge-based firms, encouraging them to remain within the agglomeration by the attraction of other oil & gas E&P equipments

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factories to the region. This policy may provide several business opportunities for the vast supplier network to operate in the niche market opened by the arrival of those companies. These non-knowledge-based suppliers will certainly have difficulties to migrate to other provinces overseas, due to the lack of knowledge and low value added of their activities. However, a particular policy for this group of firms is necessary due to the huge number of job opportunities they provide and their importance for the local economy. This strategy of working with these two policies could prevent a widespread regional recession and the probable collapse of the local economy in 4 or 5 decades ahead, by encouraging firms to remain in the agglomeration and providing substantial opportunities for their development and sustainability.

9.3. *Concluding remarks*

This paper explored how technological competences were achieved by analyzing oil & gas firms located in the Campos Basin province in the Rio de Janeiro State. Drawing on the clusters and the innovation systems discourse, this study attempted to determine the formation process and characterization of the Campos Basin agglomeration, how technological changes were implemented and whether geographic proximity was a factor that favored innovation for the firms located in the province.

Despite many empirical studies on clusters and the heated discussion about the importance of geographical proximity for innovation, this empirical study found that a broader analysis was needed to understand the emergence of the Campos Basin agglomeration. It was found that at least three elements shaped the relationship between geographical proximity and innovation: sectoral patterns within which the agglomeration was involved, local dynamics (which involved supporting organizations and policies) and the role of the firm in the value chain.

This paper shows that Petrobras was able to take advantage of the fact of being spatially close to other oilfield operators and suppliers, by interacting, absorbing and developing innovative technological capabilities endogenously, resulting in Brazilian energy self-sufficiency. This strategy also enables Brazil to be worldly recognized as the leading center for deep and ultra-deep offshore exploration and production.

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