From innovation projects to knowledge networks: the sectoral organisation of innovation in the Brazilian ICT sector

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Abstract: This paper explores the structure of the project-based innovation networks promoted by tax incentives to innovation activities in the Brazilian ICT sector ('ICT Law'). It proposes a framework for characterising the decentralised governance of innovation projects in sectors, identifying:

1 the boundaries between firms and technological partners
2 the specialisation of actors in types of activities
3 the speed of change in the collaborations between firms and technological institutes.

The empirical analysis is based on the data of more than 10,000 innovation projects conducted between 1997 and 2003. The results show a strong re-organisation of the innovation networks in the sector during the period, attributed mainly to a shift from investments in middleware to software- related innovation activities, the re-specialisation of the subsidiaries of multinational companies, and the emergence of private research institutes as central nodes inside the sectoral innovation system.

Keywords: innovation projects; knowledge networks; sectoral innovation system; information and communication technologies; innovation policy; Brazil; organisation of innovation.

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1 Introduction

Identifying relationships between the knowledge base of sectors, the role of different actors and networks, and the channels of the knowledge flows within and across sectors is a fundamental challenge for the dynamic understanding of sectoral innovation systems (Malerba, 2002; Owen-Smith and Powell, 2004). Scholars have used joint ventures, surveys on university-industry links, patents citation and co-authorship in publications as ways to measure knowledge and knowledge flows and examine the process of specialisation and formation of comparative advantages among firms, sectors and countries[1]. However, despite their key role in the organisation of innovative activities, detailed studies on networks formed around innovation projects in sectors remain particularly rare.

This paper argues that analysis of networks formed by innovation projects can provide an in-depth examination of the activities performed by different actors in innovation systems. It proposes a number of methods for examining the nature of the knowledge-related interactions in sectors based on the details of innovation projects. It argues that understanding these underlying networks in different sectoral settings can provide fundamental input for policy-makers interested in designing public-private partnerships that promote the dynamic of sectors.

This type of analysis of the networks formed by projects can be particularly useful for examining the innovation systems in developing countries. The analysis of innovation systems has become widely recognised as an approach to discussing the role of different institutions and sectoral policies in different levels of aggregation (Freeman, 1987; Lundvall, 1995; Malerba, 2002; Mytelka, 2000; Nelson and Rosenberg, 1993). The need to look at systemic interactions became widely acknowledged as fundamental for identifying the evolution of firms' technological positions (Barnett and Burgelman, 1996; Bell and Albu, 1999; Saxenian, 1991). As the underlying networks are in early stages of formation, key players and their mechanisms of interaction are still indeterminate, and interventions may result in a profound impact on the resulting organisation.

This paper uses a large database of innovation projects inside the Brazilian ICT sector. It draws upon an exclusive dataset containing details of the innovation projects conducted by national and multinational manufacturing companies as well as educational and research institutes in the Brazilian ICT sector and declared under the Brazilian ICT Law[2] between 1997 and 2003 (Brasil, 1998; Brasil, 2003). After decades of important substitution policies, the market was opened to foreign investment during the early 1990s. The previous regulation in the Brazilian ICT sector was substituted by tax incentives for the commercialisation of a set of industrialised products in the internal market conditioned to local manufacturing and investments in R&D. The R&D offset scheme implemented in the sector promoted an overall private investment of more than USD 2 billion in innovation during the last decade and involved more than 200 companies as well as 200 universities and research institutes. The ICT Law became one of the pioneering projects for the development of sectoral innovation systems in Latin America following its liberalisation policies. Therefore, from the empirical perspective, the paper sheds new light upon the structure that co-evolved from the institutional changes in the Brazilian ICT sector and the interaction between multinational and national innovation systems during the period in different technological trajectories.

This research uses 10,088 innovation projects in the Brazilian ICT sector and more than 35,000 economic transactions inside innovation projects to observe the interaction among actors. In particular, this paper examines different ways in which the type of innovative activities influences the:

1 boundaries between firms and technological partners in different knowledge-related activities
2 the process of specialisation in different governance mechanisms
3 the stability and change in the collaborative activities among actors in the sector.

Three propositions on the relationship between the knowledge base and the organisation of innovation in the sector are developed using, respectively:

1 a longitudinal examination of the boundaries between firms and technological partners in different types of innovation project
2 a project-based revealed technological advantage (PRTA) index
3 a social network correlation technique [quadratic assignment procedure (QAP)].

This analysis provides a number of insights about the reorganisation of the innovative activities in the sector during the period.

The structure of the paper is as follows. The second section briefly discusses how the potential of the innovation projects to examine the innovation systems in developing countries. Section 3 defines the innovation network and describes the dimensions examined inside this paper. Section 4 describes the characteristics of the database of innovation projects in the Brazilian ICT sector, and the main characteristics of the sectoral innovation networks. This is followed by the details of the methods used in the investigation as well as consideration of some of the limitations of the research design (Section 5). Section 6 details the results of the empirical analysis of the innovation network in the Brazilian ICT sector empirically elaborating propositions on the relationship between the knowledge base of projects and the organisation of the innovation in sectors. The last section summarises the empirical findings and outlines some preliminary implications for firm strategy and institutional design of sectoral networks.

2 Innovation projects in the analysis of sectoral innovation systems

The idea of using innovation projects as the unit of analysis for examining the creation and diffusion of innovation in sectors is not new. The early studies on innovation focused on developing large databases of the innovations introduced in specific sectors. For instance, in the 1970s, the SPRU innovation database which contains information on 4,800 radical innovations in the UK since World War II, was used to connect individual results of the project to the dynamics of industrial change (Archibugi and Planta, 1996; Rothwell et al., 2000).

In this period, the analysis of individual projects was associated with some advantages and disadvantages (Archibugi and Planta, 1996). Among the key advantages, it was highlighted that the examination of innovation projects can be a superior indicator than patents in sectors as a large part of innovation does not use this type of intellectual property protection, particularly in developing countries. The percentage of innovations for which a patent application is made varies substantially across sectors and among countries.

These numbers show that projects can be used to overcome the weaknesses in the indirect measurements of knowledge creation and knowledge flows in companies and sector. Particularly when we move away from the technological cutting edge and traditional indicators of knowledge creation, patents and scientific publications become less reliable (Meyer, 2002; Patel and Pavitt, 1993). However, despite the fact that a database on individual innovation projects provides advantages as they provide a direct measurement of innovations, some authors have claimed that they have substantial drawbacks as well. For instance, the definition of the sample is generally arbitrary, and different people consulted may have different perceptions of the relevance of individual innovations (Archibugi and Planta, 1996). In addition, it is very difficult to develop internationally comparable databases and each of the surveys has used its own design, sample definition and implementation. It is indeed difficult for authors using these databases to claim they have collected a representative sample of the innovation in sectors. It is fair to say that the difficulties in accessing reliable and comparable datasets pushed quantitative research on individual innovation projects to the boundaries of the discipline (Archibugi and Planta, 1996).

More recently, however, the development of consolidated databases on projects may reverse this trend. Innovation projects reemerged as crucial ways of organising knowledge flows among stakeholders in complex settings. The quantitative analysis of projects can provide a way to examine how companies reconciled over time the need to exploit and explore technological opportunities (Manning, 2005). Different from the concept of capabilities, innovation projects are dynamic in nature as they are more easily defined by its temporary nature and specific aims.

The recent literature on project management and innovation management has reasserted projects as crucial organisational mechanisms for evaluation of new ideas, resolution of problems and translation of knowledge into applied routines (Burns and Stalker, 1994; Davies and Hobday, 2005; DeFillippi and Arthur, 1998; Grabher, 2004b; Tidd, 1997). Innovation projects are core problem-solving mechanisms in firms and sectors (Dosi and Nelson, 1994; Nelson and Winter, 1982) and they are directly connected with knowledge-related creation, experimentation and interaction (Dosi et al., 2003; Leonard-Barton, 1992). Innovation projects are used by companies both to exploit and explore different knowledge bases for commercial and non-commercial purposes.

Naturally, projects exist in different contexts. In relation to the innovation literature, projects have been used in the analysis of organisational structure in complex product systems (CoPS) (Davies and Brady, 2000; Gann and Salter, 2000; Hobday, 2000; Hobday and Rush, 1999) and new product development (Eisenhardt and Tabrizi, 1995; Hansen et al., 2005; Henderson and Clark, 1990). It has been increasingly recognised in the literature that professional communities expand beyond organisational boundaries and are crucial for learning across organisational boundaries (Wenger, 1999).

In addition, the new opportunities opened by the ICTs mean that innovation projects are not limited to organisational and geographical boundaries. Innovation projects evolve into extended informal and formal R&D networks that acquire a very high level of technical skill in a specialised area. By cultivating a network of R&D partners, firms are able to fulfil sudden or unusual requests quickly and effectively (Brown and Eisenhardt, 1995). As expressed by Grabher, "projects hinge on a dense fabric of lasting ties and networks that provide key resources of expertise, reputation and legitimisation" (Grabher, 2004a). Therefore organisational mechanisms need to be acknowledged as more important than proximity in the analysis of knowledge in sectors (Boschma, 2005; Iammarino and McCann, 2006).

A recent stream of literature has highlighted the need for examining and comparing the whole inter-organisational networks (Sydow and Staber, 2002; Provan et al., 2007). Network analysis has emerged recently as one of the most promising tools for the analysis of the knowledge flows in innovation studies where specific rules/norms or institutions would allow definition of the boundaries of the observable network, its participants and the scope of their activities. However, a limited number of studies have targeted the networks of organisations.

By examining the structure of the networks based on project level data, this paper also contributes to this emerging empirical literature in this area (De Maio et al., 1994; Grabher, 2004a; Hellgren and Stjernberg, 1995; Windeler and Sydow, 2001). The possibility of using project level data collected during the implementation of sectoral policies provides a way to connect very closely to the sectoral dynamic induced by specific institutional settings. Although using secondary data on the economic transactions in innovation projects as a proxy for knowledge flows in sectors is certainly a simplification, it nevertheless offers many advantages and complementarities in relation to its traditional counterparts such as patents, citations and surveys. It avoids any assumptions that knowledge flow (or leakage) among firms may happen 'in the air' (Marshall, 1898), that it is costless (Teece, 1977) or that it may happen as a by-product of commercial relations (Bell and Pavitt, 1993). It reinforces the idea that intentional flow of codified types of information, as well as tacit knowledge embedded in people and constructed in organisational routines, is a requirement for organisational learning in firms and sectors (Nelson, 1994). Thus, it provides an important basis for suggesting specific strategies for their improvement the institutions and the development of the networks themselves.

Indeed, the empirical literature on inter-organisational project-based networks is still concentrated in developed countries, but could have a vast potential for the analysis of sectoral innovation systems in developing countries. Innovation projects seem to be a particularly adequate unit of analysis for the investigation of the sectoral innovation systems in the developing context. Innovation projects are a key mechanism in which interaction among organisations takes place and relevant knowledge for the various parties is constructed and transferred. Innovation projects provide a way to discuss 'relevant knowledge' according to the needs of the parties involved rather than any assumption that the knowledge developed should be new to the world (i.e., patentable knowledge).

The analysis of projects provide new ways of measuring the longitudinal evolution of innovation systems in developing countries and compare the governance structures that drive change in specific directions as well as systemic characteristics that may speed up, detain or reverse the formation of these sectoral networks.

3 Research questions

The review above suggests that the examination of innovation projects in different knowledge-related activities can provide in-depth insights into the nature of the knowledge governance in sectors and also, offer a way to investigate evolutionary mechanisms of change inside the industrial organisation.

In this paper, three specific dimensions will be used to explore the structure of the network:

1 the balance between in-house innovative activities and knowledge acquisition from educational and technological institutes

2 the patterns of specialisation in the sectoral innovation networks

3 the patterns of interaction among different types of activities.

As briefly discussed below, the debate on how innovation systems operate in these crucial dimensions is still inconclusive and empirical evidences related to these dimensions are crucial for proposing appropriate policy interventions. The analysis of project-based knowledge networks can be an important input to this analysis.

3.1 How do firms balance in-house R&D and external knowledge acquisition in different types of innovation projects?

The first dimension examines the organisational boundaries in the innovation network. When conducting innovation projects, companies develop internally new knowledge and collaborate with partners, becoming active actors in different innovation network inside the sectoral innovation system. However, we may expect that networks do not emerge in the same way in different types of activities. The decision to develop in-house specific types of knowledge or use partners in the network would fundamentally determine the characteristics of the innovation network formed. Therefore, an investigation of the type of innovative activities internalised by companies and the activities that are acquired from technological partners should provide a necessary first step in the examination of the bottom-up evolution of the project-based innovation network and its characteristics. A review of the literature would suggest two key aspects that would significantly influence the boundaries found between firms and possible technological partners in project-based innovation networks: the type of knowledge activity and the availability of external resources (i.e., dispersed resources inside the innovation network).

According to the transaction cost theories of the firm (Coase, 1937; Williamson, 1985), companies will be especially interested in developing in-house certain types of innovative activities, where the costs of searching for and identifying appropriate partners and developing and enforcing appropriate contracts are high. In contrast, companies tend to use external sources of knowledge in innovative activities when they cannot fully appropriate from their own investments. Particularly, companies would under invest in some activities such as long-term research, training and other infrastructure. In such cases, the social benefits derived from these activities would provide a fundamental rationale for government intervention (Arrow, 1962). The formation of public goods would allow individual companies to access the qualified human resources using the labour market and infrastructure or information services provided by universities and research institutes. Companies, on the other hand, would target investment at industrial R&D where they would be able to appropriate directly from their investments as long as an adequate intellectual property rights regulatory framework was in place.

It is essential however to recognise that the boundaries of the firm inside sectors are more complex than simple black-and-white distinctions between public and private knowledge (Nelson, 1989). Given the increasingly interactive nature of knowledge creation within sectors the distinctions between producers and users of knowledge are increasingly fuzzy (Geuna et al., 2003). Resource-based theorists complement this discussion, arguing that the internal importance of the accumulation of technological capabilities inside organisations is a necessary way of identifying possible technological opportunities and possible technological sources (Teece and Pisano, 1994; Penrose, 1995). Industrial networks are a result of the companies' needs to grow, balancing their internal growth with the resources available outside the firm (Pavitt, 2001). The industrial product development networks would not be driven only by exogenous factors (e.g., technology created in/absorbed from universities and research institutes), but primarily by the endogenous differentiation of the capabilities accumulated by firms in the industrial structure (Nelson, 1994; Gulati, 1999; Gulati and Gargiulo, 1999).

Different authors argue that capabilities outside the firm would not be a substitute for internal capabilities, as organisational learning would allow for economies of repetition and the formation of comparative advantages (Brusoni et al., 2001). Balancing accumulation of internal capabilities and exploitation of external sources is at the centre of the firm's technological renewal and diversification.

In many sectors, and in particular ICT, the boundaries between different agents are blurring, given the extensive need for inter-organisational linkages (Antonelli et al., 2000). The governance of innovative activities becomes increasingly diverse and complex in order to coordinate the knowledge flows between different public and private agents. Project-based innovation networks would be fundamental to combine the ability to accumulate internal capabilities within firms with governance structures that would allow a wider reconfiguration of the capabilities inside a network of organisations.

Therefore, an analysis of organisational boundaries in the project based knowledge can provide a way to avoid the dichotomy between market and hierarchy in the analysis of industrial organisation. Although companies will tend to integrate vertically the activities that provide them with comparative technological advantage, they will also need to acquire external knowledge as new opportunities arise, interacting with other groups and firms. Understanding the balance between in-house and external acquisition of knowledge may provide important insights into the evolution of the innovation network.

3.1.1 Which are the patterns of specialisation in the sectoral knowledge networks?

The second dimension is related to the process of specialisation inside the innovation network. The recent literature has shown that in contrast to a normative definition of the functions/technological areas of individual organisations inside the sector, different patterns of specialisation would emerge mainly as the result of interaction among actors that compete as well as collaborate in different forms. The empirical literature is filled of contrasts between the roles performed by different organisations in different sectors. For instance, multinational companies may have home-base-augmenting R&D sites that would tap into knowledge from foreign research activities, sending information from the foreign lab to the central or headquarters lab. They may also have home-base-exploiting R&D sites supporting foreign manufacturing or assisting in adapting standard products to foreign demand, therefore, their information flows would be primarily from the central lab to the subsidiary lab (Kuemmerle, 1997).

In relation to universities, some authors argue for the increasing 'entrepreneurial university' focusing their capabilities on developing new products that could result in high-tech start-ups translating research into new products (Etzkowitz et al., 2000). Others have pointed out that universities play a very different role in fast growing developing economies in East Asia where universities were mostly key shapers of human capital formation according to industry demands (Mathews and Hu, 2006).Similar differences are observed in the literature on research centres. In some cases, they are considered a source of dynamic comparative advantages in sectors and countries, fundamental to attracting high value added activities and world class researchers in a world with low trade barriers and increasing division of labour (Dunning, 1998; Patel and Vega, 1999). In others, particular in developing countries, public research institutes are associated with the systemic transfer of foreign technology and subsequent adaption and diffusion to local companies (Kim, 2000; Mathews and Hu, 2006). In addition, different forms of private institutes have also been increasingly acknowledged in the innovation literature as intermediary organisations that may help unveil blocked opportunities in the boundaries of the sectoral innovation systems (Rush et al., 1995; Howells, 2006; Sapsed et al., 2007).

Given the diversity of organisational mechanisms observed in different sectors and cases, identifying empirically how the knowledge base determines the distributed innovation network within sectors is an important research question.

A wider range of governance mechanisms connecting the innovation process within firms with knowledge in universities and research institutes needs to be considered in order to support the identifying and exploiting of technological opportunities within distributed networks (Fombrun, 1986; Freeman, 1991; Powell et al., 1996) There seems to be no best practice, as different organisational forms inherited specific advantages and disadvantages related to their internal dynamics. Quantitative analysis on the process of technological specialisation of organisations in sectors is still unexplored in the literature in developing countries. Nevertheless, a dynamic analysis of the specialisation is important as it might unveil differences and complementarities between the role played by national and multinational firms, universities and research institutes in the decentralised innovation process. It can shed light on the source of leadership in specific activities and help in the identification of look-ins and constraints in the complex decentralised knowledge governance in sectors.

3.1.2 How fast do inter-organisational linkages emerge and change over time?

A knowledge network is the result of its unique historical experience and is developed in a unique path-dependent process (Gulati, 1999). On one hand, a stream of research assumes a certain persistence of network structure and most of the organisational theory would point out that inertia, rather than plasticity, is the norm (Walker et al., 1997; Rumelt, 1995). The recent analysis of innovation systems in developing countries has put increasing emphasis on time and change and the need to understanding the rate of change both in terms of creation and transformation of these sectoral innovation systems (Bell, 2006). In many cases, this dynamic is explored in decades (Ariffin, 2000; Figueiredo, 2001).

However, the studies in innovation also show that stability will depend upon the context in which the network operates. In relatively stable environments, organisations and networks tend to be relatively stable as well. At the same time, networks also need to respond to changing characteristics of the environment and must evolve over time.

Technological dynamics is usually associated with significant organisational change in the structure of the knowledge networks. The analysis of secondary data on the US data communications industry shows that the emergence of new technical sub-fields results in shifting networks of strategic collaborations (Soh and Roberts, 2003).

Given their dynamic nature, many innovative organisations make use of a portfolio of projects to balance between exploitation of technological niches and exploration of new opportunities (Davies and Hobday, 2005).The speed of change in the underlying knowledge networks in sectors may provide important insights about the dynamic of creative destruction/technological accumulation in sectors. In many sectors, such as ICT, the technological dynamism is associated with blurring boundaries of the form given the extensive need for inter-organisational collaborations (Antonelli et al., 2000; Stuart, 1998). Discontinuities in technological trajectories may result in important opportunities for new companies and may disrupt existing key players in sectoral networks (Christensen, 1997). Discontinuities in networks may also be the result of institutional disruptions. The transition to open economies requires an understanding of the reaction of the different actors within the system to the new set of incentives and how this impacts the accumulation of capabilities (Kim and Tunzelmann, 1998; Radosevic, 1999; von Tunzelmann, 2004).

However, our understanding about how innovation networks change and adjust to new conditions is still very limited. It is still not clear how the speed by which the linkages inside the system respond to changes in institutional settings and technological opportunities. Examining the speed of change in the underlying knowledge networks can provide a way to examine the transformation in the sectoral systems given joint institutional and technological changes.

4 General characteristics of the database

A useful way to define the network is in terms of the broad institutions, the actors, the ties and the content of the interactions involved in it (Malerba, 2005). This paper delimits its analysis to the network formed by innovation projects declared under the tax scheme developed in the Brazilian ICT sector, called ‘ICT Law’. The tax scheme defined R&D obligations proportional to sales in the national market in exchange for different types of tax exemptions/waivers for manufacturing companies’ products. In order to be entitled to the tax scheme, the companies were obliged to invest approximately 5% of their national turnover in innovative activities.[3] Ex post, the activities conducted should be described in structured project-type forms and in turn audited by the regulatory governmental agency (SEPIN) connected to the Brazilian Ministry of Science and Technology.

Through a collaboration agreement with the Brazilian Ministry of Science and Technology, the database of projects used for administrative purposes was codified for this research. While adhering to the confidentiality requirements of the contract, this research uses the normalised procedure for collecting data from the companies as a way of exploring the relation between the types of project and the organisation of the innovation network.[4] This unique database of projects contains information from the executor of individual projects in order to identify the process of knowledge creation in different organisations and transactions among firms and technological partners to identify the process of inter-organisational knowledge flow. In terms of projects, the dataset contains 10,088 projects executed under the Brazilian ICT Law between 1997 and

2003 (an average of 1,261 per year). The costs of projects expanding beyond one specific year needed to be declared separately for the different years. The projects total an amount of R$1.6 billion executed internally by the companies and R$ 1.1 billion executed in partnership with universities and technological institutes (annual average of R$358.1 million) (see Table 1). Table 2 summarises the boundaries of the innovation network under examination following the elements discussed in Section 2.

Table 1 Longitudinal distribution of the projects

Total	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*Average*	*Total*
Investments (million R$)	304.3	346.8	389.5	560.4	249.6	349.6	306.3	358.1	2864.4
Number of projects	1,194	1,381	1,439	1,741	783	1,235	1,055	1,261	10,088
Average project size (thousand R$)	2,421.5	2,738.8	2,907.5	3,868.1	4,555.0	4,818.0	8,799.7	3,665.5	33,774.1
Equiv. full time staff	2,637.2	2,823.0	2,666.2	3,582.1	1,535.3	2,090.1	1,563.6	2,355.2	19,252.6

Note: Estimated number of full time staff
(Direct + Indirect HR costs) / (Average cost man/hour * 2000).

Table 2 The innovation network under the Brazilian ICT Law

Dimensions	*Description*
Institutions	Manufacturing companies operating under the Brazilian ICT Law were required to invest approximately 5% of the national sales in innovative activities (2.3% needed to involve a research and/or educational institute) in order to benefit from tax incentives. It resulted in more than R$2 billion invested in innovation projects between 1997 and 2003 (period under analysis)
Actors	Two hundred eleven manufacturing firms of products under the incentives developed partnerships with local institutions (51 foreign companies and 160 domestic companies)
	One hundred eighty one technological partners that met the regulation requirements (46 private research institutes, 20 public research institutes, 75 private educational institutes and 40 public educational institutes)
Knowledge	Innovation projects allowed under the incentives were classified using the following categories: laboratory and infrastructure for S&T, quality systems for R&D, training in S&T, technological services, development of products in hardware, software, semiconductors, middleware and production processes, as well as research activities.
Ties	Based on more than 35,000 transactions within innovation projects conducted under collaborative agreements between firms and technological partners.

In terms of actors, the dataset involves 211 companies and 181 educational and research institutes operating under the Brazilian ICT Law for the period 1997 and 2003. These actors are located throughout the entire Brazilian territory with the exception of the Manaus Free-Trade Zone, which receives specific incentives to manufacture and for R&D activities. The nodes of the network are companies and their 'technological partners'. The companies could be subdivided into national and multinational companies with local manufacturing of products operating under the incentives (usually products that integrate advanced electronics, such as computers, mobiles and telecommunication equipment). In turn, the technological partners could be subdivided into organisations that would fit the definition of educational and/or research institutes from either public or private ownership. The regulation defined that a specific part of the investments (approximately 40%) should be conducted with technological partners in an explicit attempt to promote university and industry linkages. These partners were especially important in the regulation that aimed to reinforce these organisations as the key nodes in the sector. The database of projects contains details on the costs of innovative activities both inside companies and with technological partners. As the regulation does not define the type of activities that should be conducted inside the firm boundaries or with partners, this database provides a useful source for investigating the firm decision making between in-house R&D and using the network of partners to conduct specific types of activities.

In terms of ties, the knowledge flows are developed on the basis of more than 35,000 transactions within the projects between firms and educational/technological. Considering that there are naturally many transactions among the same organisations, there is a total of 948 ties between these 392 nodes. These transactions are used to operationalise the flow of knowledge among the organisations in the network. There were also transactions with other companies, creating a wider, open network (commercial software companies, suppliers of equipments and training abroad, and other organisations not classified as 'technological partners' inside the network). However, the analysis of these transactions would add another layer of complexity and is therefore beyond the scope of this paper.

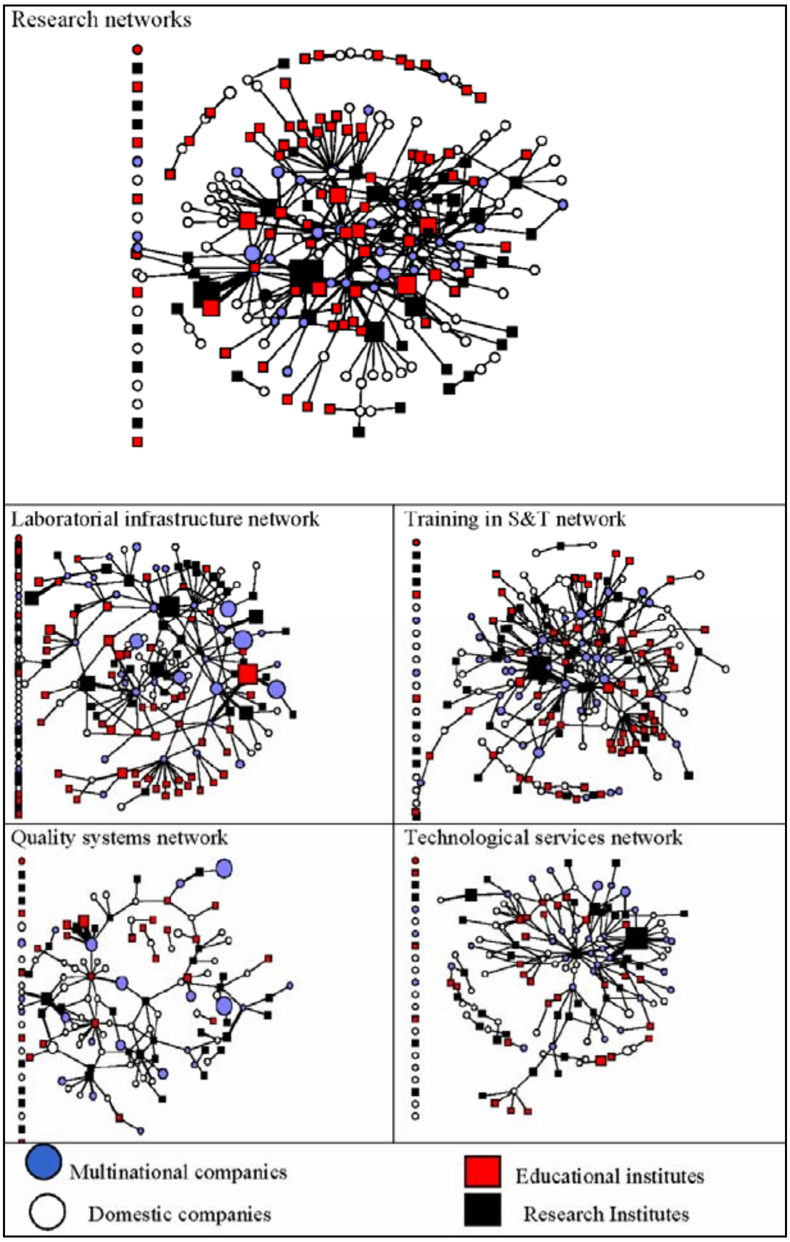
The definition of the type of activities is connected to the definition used in the standard procedures, namely investments in laboratory and infrastructure for S&T, quality systems for R&D, training in S&T, technological services, development of products in hardware, software, semiconductors, middleware[5], and production processes, as well as research activities. This categorisation at project level represents an advantage in terms of defining the knowledge base independently from the final product classification (e.g., Pavitt taxonomy, most of the sectoral system studies) as it allows the existence of multi-technology firms (Granstrand and Sjölander, 1990).

Table 3 shows the distribution of ties according to the type of activities. It also summarises some basic statistics about the network in terms of investments in projects, the number of firms, the number of ties, and the strength and density of the network divided by the different activities. Table 3 also contains some details about the density and concentration in the different networks.

Foreign companies represented 72% of the total investments, while domestic companies were 28%. The concentration is especially high among the top 20 companies. The top 20 represent 73% of the total investments. Of these 20 companies, 16 are subsidiaries of foreign multinational companies, accounting for 64%. A similar concentration can be observed among the receivers of investments. In relation to the proportion of the resources allocated to technological partners by the firms, approximately 60% of the total investments went to private research institutes, followed by private educational institutes (18%), public research institutes (12%) and public educational institutes (9%).

Figure 1 provides a visual representation of the innovation networks divided by the different activities. Companies are represented as circles and technological partners as squares. Domestic companies are represented in white, foreign companies are represented in blue, educational institutes are in red and research institutes in black. The diameter is proportional to the sum of innovation projects conducted by the specific organisation during the period between 1997 and 2003.

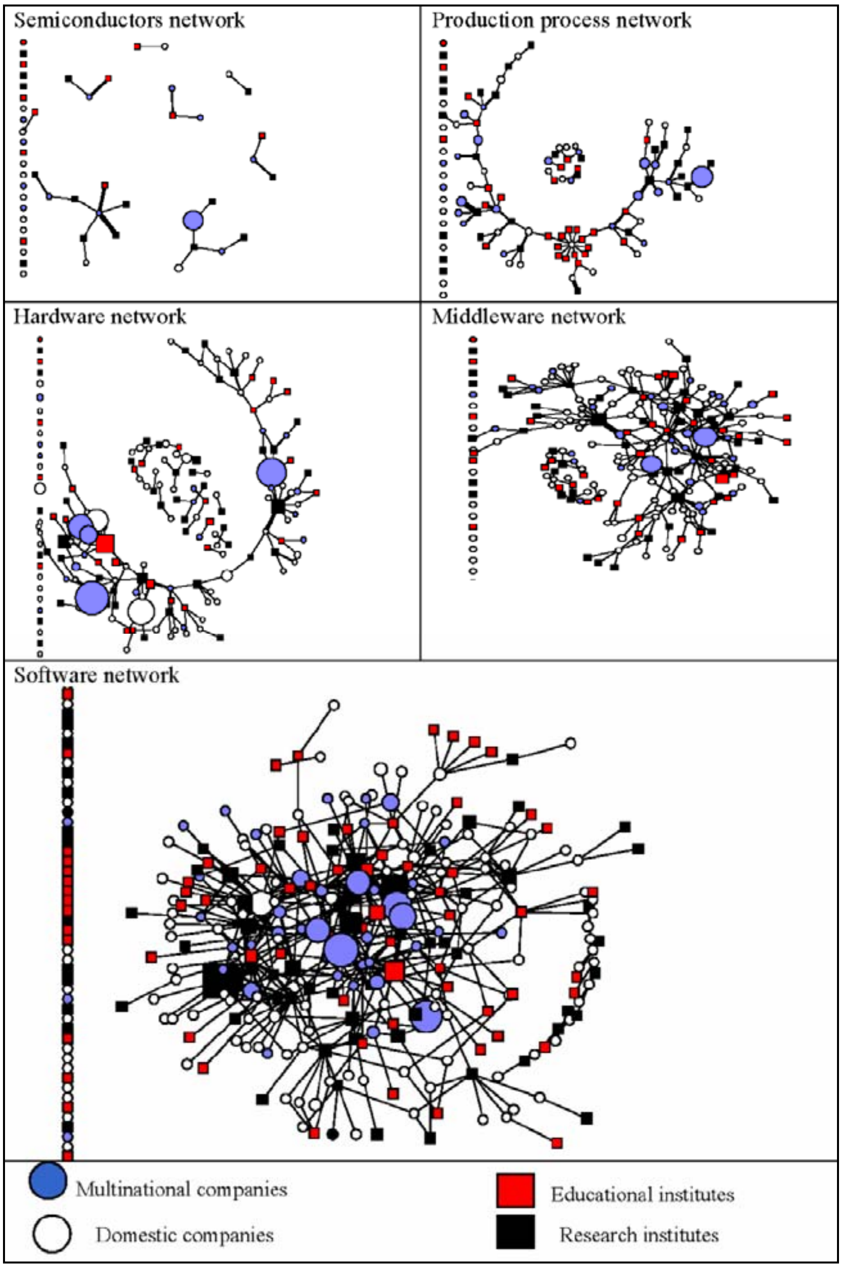
Figure 1 Innovation networks in the Brazilian ICT sector divided by type of activity between 1997 and 2003 (see online version for colours)



Note: Size proportional to sum of investments in executed innovation activities

Source: Own elaboration based on MCT/SEPIN data using NetDraw 2.37 (Borgatti, 2002)

Figure 1 Innovation networks in the Brazilian ICT sector divided by type of activity between 1997 and 2003 (continued) (see online version for colours)



Note: Size proportional to sum of investments in executed innovation activities

Source: Own elaboration based on MCT/SEPIN data using NetDraw 2.37 (Borgatti, 2002)

Table 3 Descriptive statistics about the 'ICT Law' innovation network between 1997 and 2003

Dimension	*Infrastructure*	*Quality*	*Technological services*	*Training in S&T*	*Semiconductors*	*Production processes*	*Hardware*	*System*	*Software*	*Research*
Sum of investments (million R$)	169.7	118.2	84.7	159.5	44.7	108.9	203.4	621.7	838.3	121
(with partners)	103.7	27	65.8	100.4	4	13.5	46.3	212.4	385	97.2
Number of firms	142	170	104	177	30	140	191	234	271	195
(with partners)	64	67	76	87	15	44	81	127	157	111
Number of partners	96	52	71	117	18	54	71	92	140	121
Number of ties	174	120	162	240	22	90	141	230	425	304
(>R$ 1 million)	18	5	12	20	1	3	8	31	56	23
Tie strength (thousand R$) average	570	174	387	388	189	145	304	799	830	309
Tie strength (thousand R$) maximum	11,584	3,349	20,957	28,565	1,427	1,818	7,300	28,188	58,622	9,229
Concentration – (10-firm ratio)	73%	53%	72%	70%	99%	63%	63%	64%	70%	65%
Concentration – (5-firm ratio)	42%	36%	51%	51%	97%	47%	48%	49%	45%	48%
Concentration – (3-firm ratio)	26%	26%	40%	41%	95%	38%	34%	36%	29%	37%
Concentration – (1-firm ratio)	9%	10%	25%	25%	72%	23%	13%	16%	12%	18%

Source: Own elaboration based on MCT/SEPIN data

Before entering into the characteristics of these networks, it is useful to observe the relevance of the innovation projects database compared to the total investments in innovation in the Brazilian telecommunications and computers sector. One way to proceed is to compare the results with an external measurement of the total investments in R&D conducted by these two sectors. The total investments in R&D in the telecommunications sector and the computer sector by private companies as assessed by the PINTEC (Brazilian innovation survey) were R$627 million in 2000 and R$637 million in 2003 according to the two innovations surveys conducted in the Brazilian ICT sector (Brasil, 2007). In addition, the innovation survey estimated that the total outsourcing of R&D was R$153.9 million in 2000 and R$184.2 million in 2003.

From these figures in this section, it is possible to estimate that the SEPIN database contains on average more than 55% of the investments in R&D in the computer and telecommunications sector (the average annual investment under the ICT Law was R$386 million for the entire period). In addition, more than 85% of the innovation projects outsourced occurred inside the regulatory framework.[6]

Although there are some differences in the concept used to classify R&D in the two databases, the overall number obtained via these two different databases illustrates two general observations about the dataset:

1 There is possibly more R&D activity within companies in the sector, as it contains a much larger sample, such as software companies and services that do not have a manufacturing production system with products/minimum standards required by the regulations. Anyway, the number of projects in the dataset is indeed a significant proportion.

2 Almost the totality of the outsourced R&D in the computer and telecommunications sector was conducted under the regulation. Therefore, in general, we assume that the project and the ties pointed to here do provide an important measurement of the investments that the companies would make inside the limits of the sector under analysis.

5 Research methods

The methods used for the investigation of each one of the research questions are presented in this section. In order to examine the first research question ('How do firms balance in-house innovative activities and knowledge acquisition from educational and technological institutes?'), the relative amount of investments and boundaries between in-house and outsourced innovative activities are explored in ten different types of innovation activities throughout the allocated time period. Managers classified individual projects among the following categories: infrastructure to R&D, technological services, training, hardware, middleware, software, semiconductors, process technology, other types of product development, and research. They were also allowed to attribute a specific percentage to projects that involve more than one category. The different networks visualised in Figure 1 are analysed using the trend (two years average) for the investments in the different types of knowledge-related activities and within the locus of execution of the projects (firms or technological partners). In case where projects involve more than one category, the percentage suggested by managers was used to distribute the overall investments among the different categories. The significance of the differences between the different groups was verified using an ANOVA test (Appendix).

In order to explore answers for the second question ('What are the patterns of specialisation in the innovation networks?'), a specialisation index was adapted from the revealed technology advantage (RTA) index[7]. In our case, we use the value of projects conducted by the organisation to arrive at the PRTA index calculated for the different types of organisations (i.e., foreign companies, domestic companies, public and private research institutes, and public and private educational institutes) for the different types of knowledge activities. The project-based specialisation index (PRTA) could be defined as:

$$PRTA_{ij} = \frac{\left(P_{ij} \Big/ \sum_i P_{ij} \right)}{\left(\sum_j P_{ij} \Big/ \sum_{ij} P_{ij} \right)}$$

PRTA project-based revealed technological advantage

P_{ij} costs of the innovation projects executed by organisational type *i* in knowledge related activity *j*.

The governance mechanisms were divided among foreign companies, domestic companies, public and private research institutes, and public and private educational institutes. P_{ij} was the costs of the project executed by organisational type *i* in knowledge related activity *j*.

As in the traditional RTA, values greater than one suggest that an organisational type is comparatively specialised in the innovative activity in question relative to other organisational types (as it conducted more projects in this activity than the general average for the group), while values less than one are indicative of a position of comparative disadvantage. This procedure would allow one to control for the general concentration of specific organisations as well as the rules that define broader proportions that should be spent in companies and technological partners.

Finally, to examine the third question ('How fast do inter-organisational linkages change over time?'), a correlation analysis is used to investigate the interdependence between the structures along time and among different networks. In specific, the QAP is used to investigate these changes. QAP is a method that has been used in social network analysis, and is useful for analysing dyadic data sets. It provides a measurement of the correlation between two networks. For instance, if for a given group, all the relationships of friendship are also business relationships, the result of the correlation will be one. If for another group, friendship and business do not work hand in hand, the QAP procedure will tend towards zero.

First, the QAP procedure is used for all the possible combinations of the ten knowledge networks (i.e., for each type of activity) in different years (between 1997 and 2003). This provides the degree of change in the network over time. Each network structure is represented by a valued matrix (Aikk), where i is the year and k is the number of organisations in the network. In this case, k is constant and equal to 392 as there are 212 firms and 180 technological partners in the network. The values of these networks are the sum of the transactions among partners (i.e., valued network). This procedure was also implemented based on a binary network.

The mathematical procedure could be defined as:

$$\text{Xii} = \begin{pmatrix} \text{Corr(A1kk}\,|\,\text{A1kk)} \cdots \text{Corr(A1kk}\,|\,\text{Aikk)} \\ \vdots \qquad\qquad \ddots \qquad\qquad \vdots \\ \text{Corr(Aikk}\,|\,\text{A1kk)} \cdots \text{Corr(Aikk}\,|\,\text{Aikk)} \end{pmatrix}$$

The result of the correlation is a matrix (Xii) containing the strength of the overlap between each pair of networks. Secondly, an additional QAP is used for investigating the relationship between the ten different knowledge networks. This provides a cross-activity correlation. In the case under analysis, the network structure in each one of the ten types of activities is represented by a valued matrix (Aikk), where it is the type of activity and k is the number of organisations in the network. Again, k is constant and equal to 392 as there are 212 firms and 180 technological partners in the network. Based on the empirical evidences, three propositions are proposed on how the knowledge base of innovation projects influences the organisation of the innovation in sectors.

6 Results

This section describes the results from the empirical examination of the innovation network. The aim of this analysis is both an initial exploration of the specific development of the innovation network in the Brazilian ICT sector during the period and the development of in-depth insights about the structure of the network.

6.1 The boundaries between in-house R&D and outsourcing activities to technological partners

The first research question is related to the balance between hierarchies and markets in innovation activities inside the innovation network. In order to explore the dynamic of the formation and interaction among the innovation networks, Figure 2 shows the trends in the accumulated technological capabilities in the different technologies (estimated based on the percentage of the total investments) and the balance between in-house R&D and acquisition of external innovative activities in different networks (based on the sum of investments in projects controlled by the company compared to those outsourced to technological partners).

Firstly, Figure 2 reinforces the visual inspection of the networks represented in Figure 1:

1 there are incipient networks related to semiconductors, the production process and hardware

2 wider networks with relatively weak ties were formed via activities such as training, technological services and research

3 there are strong-tie networks in middleware and, most of all, software, where considerable governance mechanisms could be expected through the technological partners.

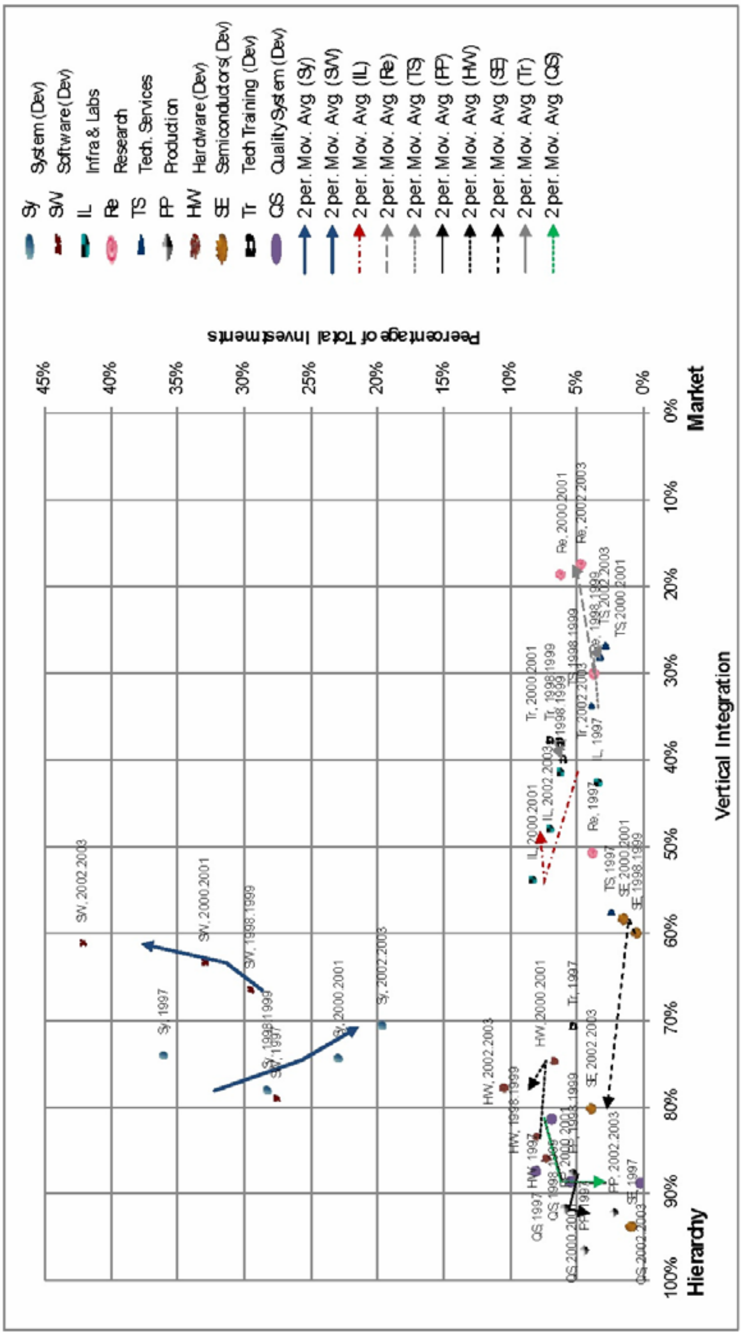
Secondly, these three groups are significantly different in terms of boundaries of the firm in innovative activities and accumulated capabilities, as supported by the ANOVA test (Annex 1).

The different characteristics would allow the categorisation of the networks in three groups.

The first group is called here *enabling networks* and they are characterised by low levels of investment and low vertical integration. The group refers to the points at the bottom right and they are associated with activities such as training in science and technology, technological services (e.g., metrology, certification) and research activities. Companies tended to use the market in these innovative activities with relatively lower investments. Investments within innovation projects tend to be smaller and almost entirely outsourced. Only a smaller part of the investments in technological services (36%), training in S&T (45%) and research activities (22%) were conducted internally.

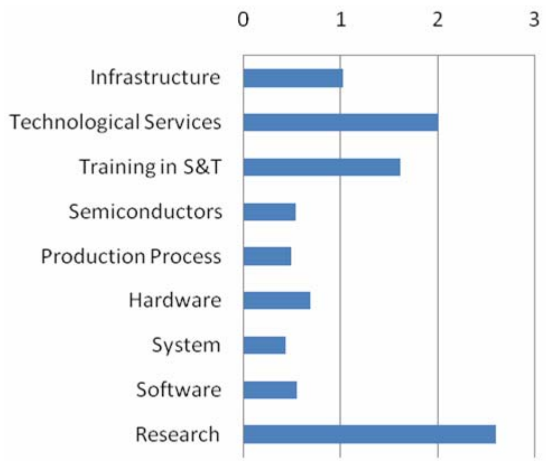
To some extent, investments in infrastructure and laboratories could also be associated with this group, although they have a less significant difference in terms of firm boundaries (46%).

Figure 2 The size and boundaries of the innovation networks in the Brazilian ICT sector (see online version for colours)



These ties with external organisations were also weaker. In fact, when considering number of ties in relation to the total investments, there are just 1 tie/million reais in infrastructure and laboratories projects, 1.6 ties/million reais in training projects, 2.1 for technological services and 2.5 for research activities. These numbers contrast significantly with averages of 0.4 to 0.6 ties per million reais invested in the other 'product development' networks (Figure 3).

Figure 3 Number of ties per million of reais in different innovation activities (see online version for colours)



Although weak ties are usually assumed to be related to research projects (as companies would look for technologies opportunities based on these types of activities), it is clear that these other networks also have a fundamental connection between firms and a large number of different supporting organisations. These ties would be important for the development of human resources, technological information and so on. Some of these supporting organisations (providers of training, technological services, infrastructure, etc.), which are sometimes neglected within innovation studies, need to be understood in more detail as they cannot be assumed to be available in most developing countries.

The second group is called *developing networks* and they are also characterised by low levels of investment, but with high vertical integration in the innovative activities. Individual companies tended to conduct most of their product development projects in-house whenever there were limited total investments in specific technologies. The points at the bottom left were mainly composed of three groups of innovation activities during different time periods: product development using hardware, semiconductors and production process technology as well as quality systems. An important aspect of these three arrows is the strong internalisation of the technological investments inside firms, and although some linkages could exist with international partners or other stakeholders, there was very limited horizontal collaboration with partner technological institutions. This indicates that in these networks the companies resisted using external sources of technology. This analysis reinforces the visual analysis (Figure 1) that the formation of disperse governance mechanisms has been limited in these activities.

There are also very different trends in this group of networks, as shown by the arrows. The arrow related to semiconductors shows incipient, but increasing, initiatives to accumulate technological capabilities inside the companies. An opposite trend is observed in relation to production technology that has decreased and outsourced activities. The arrow and the dots related to hardware show that there is an upward movement, although it has been turbulent throughout the period, probably as a result of the instability in the initiatives undertaken by different companies in this type of technology.

The final group is called *developed networks* and they are associated with high levels of investment and intermediate vertical integration of innovative activities. A different portrait could be developed around the dynamic involving the two largest networks: the networks formed by product development projects using middleware and software technology. They are both characterised by higher levels of investment and an intermediate level of desegregation of the activities between hierarchies and partnerships.

The analysis of these trends over time shows that the development of the network evolved in opposite directions. From this trend, we can infer that the established and newcomer companies have shifted their investments from middleware to software during this period. In the middleware network, while the investments in middleware technology were reducing, companies tended to retain internal projects rather than consolidate. At the same time, the companies that were increasing their investments in software identified existing capabilities available in partners and the general vertical integration decreased.

In the two large areas of investment (software and middleware), the data implies that there was considerable scope for governance structures with strong ties among partners. These lower levels of vertical integration in relation to other types of product development innovation networks support the proposition that as there are increasing resources available in the network, governance mechanisms would tend to emerge and integrate disperse resources. When these capabilities decrease, as in the case of middleware, the level of vertical integration tends to increase simultaneously. This supports a resource-based view, where the evolution of the innovation networks is mainly connected with endogenous differentiation among companies in product development activities. The number of ties per total investment is significantly lower in product development when compared to training, technological services and research activities. It suggests that firms have fewer, but strong, ties in product development, while companies will also tend to have more, but weaker, ties in relation to technological services, training and research activities.

These findings support the first proposition that the boundaries between firms and technological partners in innovative activities are influenced both the type of activities and the need to integrate disperse resources. These findings also contain a dynamic portrayal of the dynamic occurring inside the sector during the period. In the development of new products, the technological opportunities identified by the companies changed considerably during the period, mainly from middleware to software. Clearly companies inside the framework identified limited opportunities in microelectronics, hardware and production processes showing that the same institutional framework can result in very different investment behaviours. Therefore the understanding of the technological trajectories opened to specific sectors cannot be overstated when examining firm behaviour.

6.2 *The functional differentiation of different types of actors in the innovation network*

A next step is to expand the analysis from the simply bilateral relation in terms of vertical integration, to the analysis of the emerging role played by different actors inside the innovation network. As previously discussed, the exact function performed by different groups of actors in the sectoral innovation system is a result of the co-evolutionary process in each sector. Despite some similarities, authors differ substantially concerning the role played by multinational companies, different private and public research and educational institutes in a developing context in contrast to developed ones. This is however a crucial question for the understanding of the sectoral innovation system, and indeed, the examination of the pattern of specialisation in the project innovation networks can provide empirical insight in this direction.

Table 4 shows the measurement of the PRTA for the different governance mechanisms.

Table 4 Revealed technology advantage of the different organisational mechanisms

		Enabling networks				*Developing networks*				*Developed networks*	
Specialisation index	*Count*	*Research*	*Training*	*Infrastructure*	*Tech services*	*Hardware*	*Semiconductors*	*Process*	*Quality*	*Software*	*Middleware*
Foreign companies	51	0.25	0.72	0.83	0.42	0.96	*1.77*	*1.79*	*1.26*	*1.08*	*1.06*
Domestic companies	160	0.58	0.61	0.53	0.49	*2.18*	0.97	0.77	*1.64*	0.69	*1.38*
Private research institute	46	*1.33*	*1.46*	*1.31*	*2.39*	0.41	0.14	0.22	0.43	*1.17*	0.77
Public research institute	20	*3.08*	0.65	0.51	*1.57*	0.49	0.29	0.45	0.21	0.89	0.73
Private educational institute	75	*2.15*	*1.25*	*2.26*	0.98	0.17	0.02	0.20	0.67	*1.02*	0.97
Public educational institute	40	*4.98*	*3.39*	*1.55*	0.32	*1.85*	0.56	0.31	0.20	0.51	0.35

In Table 4 it is possible to observe patterns of specialisation in the different nodes, thereby identifying how the knowledge base was associated with different governance mechanisms in the network (i.e., PRTA > 1). Analysing the results, some patterns of specialisation emerged in the enabling, developing and developed networks.

The results show how different technological partners had a prominent role in specific enabling networks. Among the technological partners, private research institutes became key players in the different enabling networks such as research activities (1.33), training (1.46), technological services (2.39) and development of labs and technological infrastructure (1.31). Meanwhile, public research institutes became highly specialised in research (3.08) and technological services (1.57). It is possible to speculate on the organisational characteristics that define these differences. Educational institutes, both private and public organisations, specialised in similar areas such as research, training and infrastructure (as possibly expected). Public educational institutes, a group composed mainly of federal and state universities, were particularly specialised in the research and training areas (4.98 and 3.39 respectively). Most likely, the public organisations developed their comparative advantage from their traditional role inside the structured national educational system financed with public resources.

Companies had a particular role in development activities, both in developing and developed networks. Domestic companies focused their investments in middleware and hardware (as well, demonstrated relatively higher investments in quality systems), foreign companies were predominant in emerging software network (1.08 for multinational against 0.69 in domestic firms). The latter also undertook important initiatives in the smaller semiconductors (1.77) and production process (1.79) activities. The results provides a strong indication that while domestic companies tend to be more connected to their manufacturing base in hardware (2.18), multinational companies tend to be more capable of diversifying into distinct competences in middleware and software projects. The organisational characteristics of the multinational companies may have allowed subsidiaries to develop capabilities in niches inside the international division of labour as a corporation operating in global projects and disconnecting themselves from the manufacturing basis and local market.

The differences between developed and developing networks are characterised by the increasing importance of technological partners, particularly private research institutes in this community. The participation of technological partners is clearly more prominent in these activities than in developed networks. The role of private research institutes (1.17) and, to a lesser extent, educational institutes (1.02) in software is also worthy of notice. Their prominence demonstrates the importance that these organisations have on this developed network, providing therefore an important element for coordination of knowledge related to product development.

The public nature of some technological partners seems to negatively affect their participation in product development. Traditional public institutes did not tend to diversify into collaborative activities in the new technological areas. The indication is that public funds tended to complement private investments in terms of technological services and the research personnel required for these activities, creating a relative comparative advantage for these activities. Meanwhile, the governance of these organisations and their policies could be too rigid to adapt to the short-term requirements of companies, as private research institutes became fundamental inter-organisational linkages in the software project-based networks.

This pattern of specialisation sheds new light on the distributed innovation process following the liberalisation of the sector. Recent academic discussions in the sector have been heated as authors investigate different patterns, for instance that the process of liberalisation resulted in decreasing capabilities in the cluster previously concentrated in domestic firms in Campinas (Szapiro and Cassiolato, 2003), the active role of policy and multinational equipment manufacturers in the sector (Mani, 2004), and the dependence of the innovation system in software on multinational companies in Brazil (Stefanuto, 2004). The pattern of specialisation described above shows how these different governance structures co-evolved as a result of the mixture of technical change, foreign direct investment and sectoral policies. It could be observed from Table 4 that foreign companies, private research institutes and (to a small degree) private educational institutes could be considered key nodes integrating disperse capabilities inside the fast-expanding software innovation network in Brazil.

The following proposition examines how these organisations may in fact result in distinct communities within the sector, restricting knowledge flows among specific agents.

6.3 The speed of change in the innovation network and interaction among different activities

Another crucial empirical question in the characterisation of knowledge networks is the investigation of its speed of change in the collaborations inside the network. As discussed earlier, some authors argue that these are relatively stable over time given the lengthy periods of time required to accumulate significant technological capabilities. Others have argued that the different organisations quickly recombine their partnerships following specific strategic needs and changes in the environment.

An empirical examination of the speed of change in the project-knowledge networks can inform our understanding of how companies exploit and explore technological niches as based on a QAP method, Table 4 show the correlation between the knowledge networks in different years considering valued ties. As could be expected, there is a slow decrease in the correlation among the networks as they are further apart in terms of time. Strong correlations are observed among (up to 0.88 between 1998 and 1999). The exception is between 2000 and 2001 when a change in the legislation including regionalisation requirements for the partners caused considerable disruption. (The correlation was just 0.17, showing considerable disruption).

A relevant aspect of these correlations is the fact that the structure of the network changed very substantially during the observed seven year period. As shown in the correlation between 1997 and 2003, the correlation between the two networks is less than 0.06 points if the binary network is considered, or 0.13 points if the valued ties are used. This indicates that a substantial transformation in the patterns of collaboration occurred in the sector during the period under investigation.

Table 5 Longitudinal correlation in the project-base knowledge networks in the Brazilian ICT sector – (valued ties)

	a97	*a98*	*a99*	*a00*	*a01*	*a02*	*a03*
a97	1.00						
a98	*0.88*	1.00					
a99	*0.67*	*0.79*	1.00				
a00	0.67	0.71	*0.83*	1.00			
a01	0.17	0.19	0.14	0.18	1.00		
a02	0.47	0.47	*0.60*	*0.71*	0.38	1.00	
a03	0.13	0.24	0.46	0.33	0.10	*0.53*	1.00

Although in part, path dependence in the partnerships did exist in the sector, a high-level of volatility in the project-based knowledge network is also clearly observed. The data indicates that considerable volatility was induced by changes in the legislation between the first and second half of the period. As could be expected, those periods with relatively stable legal framework had a stronger stability in the structure of the network. This, however, is not the only determinant as considerable changes also occurred during years with stable legislation. Another step in the analysis of the collaboration is the examination of the interconnection between the different knowledge flows that occur inside and among different project-based knowledge networks. Table 6 shows the result of correlation among the different valued networks using the payments within innovation projects as a proxy for knowledge flows among actors in different activities.

Table 6 QAP Correlation among the knowledge networks developed in different activities

		Enabling networks				*Developing networks*				*Developed networks*	
		ninfra	*ntrain*	*nser*	*nres*	*ncomp*	*nhard*	*nproc*	*nqual*	*nsof*	*nsys*
Enabling networks	*ninfra*	1.00									
	ntrain	*0.58*	1.00								
	nser	0.28	0.17	1.00							
	nres	0.33	0.18	*0.62*	1.00						
Developing networks	*ncomp*	0.05	0.04	0.10	0.31	1.00					
	nhard	0.16	0.10	0.04	0.24	0.15	1.00				
	nproc	0.45	*0.67*	0.15	0.20	0.14	0.24	1.00			
	nqual	0.28	0.20	0.20	0.36	0.09	0.21	0.20	1.00		
Developed networks	*nsof*	0.31	0.45	0.33	0.37	0.07	0.16	0.30	*0.58*	1.00	
	nsys	0.26	0.27	0.21	0.29	0.06	0.14	0.16	0.42	*0.60*	1.00

Note: *All the correlations are significant at 0.01.

Source: QAP procedure performed in UCINET 6 (Borgatti, 2002)

The first clear result of the correlation is that the knowledge flows inside the project-based networks are not homogeneous therefore the proposition is supported: different types of knowledge bases require specific types of inter-organisational channels. Although the relationship between the different activities does exist, most of the networks presented are significantly different from each other as demonstrated by the relatively small correlation between the different networks in most cases. Different knowledge activities would create significantly different communities of practice that could co-evolve in the sector. The second set of results with empirical relevance refers to those networks that do have a relatively strong correlation. Establishing 0.5 as an arbitrary threshold to a strong relationship, just five intertwined networks could be distinguished.

These intertwined networks could be further grouped into three distinct communities of practice:

The first strong correlation is between collaborations in training and infrastructure, and training and production technology. The analysis suggests that companies connected with the same partners for the improvement of the infrastructure and for training in new technologies. In addition, production technology was also particularly related to training in new technologies.

The second strong correlation is between collaborations in research and technological services. Other channels became specialised in providing research activities and technological services (metrology) for the companies. It is interesting to note that, in general, research and technological services (possibly centres of excellence in different technologies) were not strongly related with the linkages involved in product and process development. Finally, there are strong linkages between collaboration in product development in software and quality systems and software and middleware. Specific channels became related to the improvement of quality systems in R&D (e.g., CMM certification) and the development of products in software. Here, it is also possible to observe a strong relationship between the formation of the capabilities in middleware and software. Although this test does not allow us to attribute causality, the dynamic changes shown in Table 6 reinforce the interrelation between the decreasing middleware project network and the growing software project network. While the newcomers (especially multinational companies) shifted their investments towards opportunities in software, private research institutes became key integrators between 'old' and 'new' opportunities.

7 Analysis and implications

This research suggests that the examination of innovation projects in different knowledge-related activities can provide in-depth insights into the nature of the knowledge governance in sectors and also, offer a way to investigate evolutionary mechanisms of change inside the industrial organisation. Based on the analysis of innovation projects, this research uses a number of different methods to provide insights into the nature of the interaction inside the innovation system emerging in the Brazilian ICT sector. A number of characteristics connecting the knowledge-base of the innovation projects and the structure of the knowledge networks have been examined.

First, the research examines how firms balance in-house R&D activities and external knowledge acquisition in different types of innovation projects. Following a resource-based view of the project knowledge networks, the empirical findings support the literature that both the type of activities and the need to coordinate disperse resources influence the boundaries between firms and technological partners in the sectoral knowledge network. Innovation projects are used as a way to break into organisational boundaries and to explore the spectrum between market and hierarchies (i.e., networks) in different sectoral activities. The results show that in-house R&D activities are related to product and process development activities in innovation projects, while outsourced R&D activities are related to other non-product development activities. There are clear differences between innovation activities that would promote decentralised networks or vertical hierarchies inside the sector. While in-house R&D activities are related to product and process development activities in innovation projects that include hardware, software, semiconductors, middleware and quality systems, outsourced R&D activities are related to other non-product development activities such as training in S&T, technological services and research. The results also show that increasing investments and rapid change increase the need for coordinating knowledge in the network. The two networks with higher level investments (middleware and software) exhibit a balance between outsourced and in-house R&D. There was an important shift in the investments from middleware to software both in-house and with technological partners.

Secondly, the patterns of specialisation in the sectoral knowledge networks were explored. The results show that different types of knowledge bases are required by different organisational mechanisms resulting in long-term specialisation in the knowledge network. Inside the project-based networks, foreign and domestic companies, educational and technological institutes, public and private organisations specialise and co-evolve performing specific functions inside the sectoral system. The analysis of a project-based knowledge network provides an assessment of each of the functions which are performed by different types of organisations providing insights on how the sectoral innovation system really worked during the period. The analysis of the patterns of specialisation shed new light on the distributed innovation process occurring in the Brazilian ICT sector. The results show that foreign companies, private research institutes and (to a smaller degree) private educational institutes become key nodes integrating disperse capabilities inside the quickly expanding software project network in Brazil.

Thirdly, the speed of change and interdependence in the inter-organisational linkages of the knowledge networks is examined. The analysis of the stability and change of the knowledge network in different activities is important to understand how the technological capabilities are created and new sources of technology are explored. The results show that the changes in the inter-organisational patterns in the sector were very intense. In the short run (one-year time span), the knowledge network has been relatively stable (up to 88%) although technological change as well as discontinuities and modifications in the institutional framework may significantly impact the knowledge network. Between the first and last year of the sample – 1997 and 2003 respectively – less than 5% of the knowledge network was the same. The correlation between networks in different activities also shows that different types of knowledge bases require different types of inter-organisational channels. The decomposition of the knowledge network in different activities allows for the investigation of the characteristics of the superimposed inter-organisational networks involved in the innovation process and the complexities of their alignment in sectors. The analysis shows that knowledge networks are not homogenous structures as usually portrayed in most of the recent literature on the topic. They are formed by different superimposed and relatively independent communities of practice. In the specific sector, the strong shift in the demand between middleware and software has resulted in an important interdependence between these two networks. The correlation between quality systems and developed capabilities also shows the importance of this activity during the catching-up process.

These results provide a number of contributions to the empirical literature in inter-organisational knowledge networks. First, there are still very few empirical studies examining whole networks, particularly inter-organisational business networks. Using project level date, it was possible to examine the longitudinal process in the network in the Brazilian ICT sector, a key sector in an important emerging economy. This paper suggests and applies a number of new methods for examining the specialisation and interdependency in knowledge networks inside sectors. Specialisation, differentiation and integration (interdependence) were demonstrated to be valuable dimensions in understanding the diffusion of tacit knowledge inside and among companies. A combination of traditional and non-traditional network properties provided key insights into the dynamic evolution of the network.

In addition, the literature on sectoral innovation systems, particularly in developing countries, has just recently started to acknowledge the need for longitudinal measurement of the underlying knowledge networks in sectors. An exclusive focus on the accumulation of capabilities tends to neglect the division of innovative labour occurring between the firms and their technological partners in the same sector. The analysis of networks in developing countries adds to the usual 'technological ladder' approach to investigate the underlying principle of the formation of dynamic comparative advantage sectors in developing countries. The examination of the structure of the networks in developing countries contributes to this literature and intends to avoid a linear definition of the accumulation of technological capabilities by explicitly discussing the different functions involved in the sectoral innovation systems in developing countries.

In addition, by examining the knowledge network under the Brazilian ICT Law, it was possible to observe a factor that is far less explored in this literature, that is, the interdependency between sectoral systems such as those related to software, hardware, training, research and others. Particularly relevant in this case is the major shift in the investments from middleware to software. It shows a case where innovation projects were the key ways used by companies to change their core capabilities in a relatively short period of time. The growth of the capabilities related to software within the core nodes of the actors involved in middleware technologies shows that the changes in the portfolio of projects of multinational companies and reorganisation of teams permitted this shift.

This quantitative analysis should also be combined with qualitative methods in order to understand the in more details the emerging configurations and the dynamics of the network development (Perini, 2010). In most of the literature on networks, the characteristics of individual nodes are overlooked. The combination of quantitative and qualitative methods for examining the network would allow a deeper insight into the evolution of the network. Future complementary qualitative studies of the nodes will us to understand how agents bend rules to their advantage along the dynamic development of the network. Quantitative and qualitative approaches provide complementary insights into the network evolution, and the way one could use an understanding of the networks to suggest interventions to promote these communities.

Finally, although the network is deeply influenced by the context of the tax regime which was present between 1997 and 2003, there is no reason to constrain the utilised methods to this unique source of funding. A project level analysis of the knowledge networks could encompass other forms of funding organised by projects, a common modality in grants or other forms of support for innovation. As other sources of funding emerge (e.g., sectoral funds, local agencies, etc.), the analysis of these networks could help the development of realistic sectoral strategies in the different developmental aims.

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Notes

1 For a review of different uses of data to map knowledge flows, see Meyer (2002).

2 The ICT Law here refers to Law No. 8.248/1991, amended by Law No. 10.176/2001.

3 This percentage decreased slightly during the last three years of the analysis. See http://www.mct.gov.br/sepin for more details about the regulatory framework.

4 Three datasets were accessed in the Brazilian Ministry of Science and Technology in Brasilia for three different periods under a non-disclosure agreement and for academic purposes only. The dataset was cleaned and integrated into the different levels of analysis. The consolidated data about the network was based on the dataset of the innovative projects developed by companies for the period between 1997 and 2003, declared under the Brazilian ICT policy.

5 The original classification was 'System (hardware + software)' characterising projects in the interface. The term 'system' was substituted here for 'middleware' to avoid confusion with sectoral systems.

6 It is supported by interviews with members of institutions.

7 The index is usually used with patent and scientific publications.

Appendix

Descriptive statistics, tests and test of equality of group means

Table A1 Mean values of the different groups of innovation networks

Network type		*Mean*	*Std. deviation*	*Valid N (listwise)*	
				Unweighted	*Weighted*
Developing networks	Investments	.0490	.03090	16	16.000
(SC + QS + HW + PP)	Internalisation	.8310	.11032	16	16.000
Developed networks	Investments	.2996	.07171	8	8.000
(SW + SY)	Internalisation	.7106	.06686	8	8.000
Enabling networks	Investments	.0512	.01731	16	16.000
(Re + Ll + Tr + TS)	Internalisation	.3982	.14289	.16	16.000
Total	Investments	.1000	.10780	40	40.000
	Internalisation	.6338	.23080	40	40.000

Table A2 Tests of equality of group means among enabling, developing and developed networks

	Wilks' lambda	*f*	*df1*	*df2*	*Sig.*
Investment	.121	134.455	2	37	.000
Internalisation	.250	55.394	2	37	.000