Technological Capabilities in Argentina, Brazil and Chile

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PART III: R&D AND TECHNOLOGICAL CAPABILITIES AS DRIVERS OF INNOVATION IN BRAZIL

1. Introduction

An overview of Latin American industrial reality reflects the lack of deep and sophisticated TCs. During the import substitution industrilization (ISI) period, most domestic firms have been doing some haphazard efforts to produce for domestic markets, in many cases without any interest in exporting. Unfortunately, these efforts did not result in the accumulation of enough knowledge to survive the successive trade liberalization that arrived some years later. With the openness to foreign competition, the survivor agents were constrained to change their technological behaviour, starting by acquiring foreign embodied knowledge through fixed capital investments. The scope was then increased, to incorporate technology from the industrialized countries and to adapt it to the local conditions. This process negatively affected, in particular, many capital goods' firms, leaving them with a major setback. Many firms also undertook organizational processes changes, which meant, in some cases, deverticalization (imported inputs); while, in others, suppliers and contractors were integrated.

Firms' decisions in acquiring external technology on the one hand, allowed the rejuvenation of their capital stock, but, on the other hand, they prevented them from building sophisticated TCs. Consequently, in most of the cases, due to different reasons (from macroeconomic uncertainty to the lack of R&D and financial assistance), complex TCs were not created within firms in these countries. The interruption of their learning processes and their knowledge accumulation left the industrial systems far from the technological frontier, hampering firms from exporting and innovating.

The theoretical basis suggests the need to move away from the neoclassical theory that argues that set productive factors are available to every firm in all the countries, without additional costs. The only admissible differences are then restricted to movements along the production function. Conversely we maintain in this thesis that not all firms are equally efficient along the production function and that their specific learning or technological efforts are necessary and relevant.

We analyze these countries under an "unconventional" approach to the issues of technology in developing countries. This vision assigns a central role to firms' indigenous technological efforts in mastering new technologies, adapting them to local conditions, improving on them, and exploiting them overseas. Technology is not instantaneously and costlessly accessible to any firm. Each firm has to exert considerable absorptive efforts to learn the tacit elements of technology.

The "evolutionary theories" developed by Nelson and Winter (1982) indicate that technological knowledge is not shared equally among firms. Transfer necessarily requires learning because technologies are tacit. To gain mastery of a new technology requires skills, efforts, and investment by receiving firms. This new approach to technology involves not only the physical equipment and processes, but also procedural and organizational arrangements.

Different approaches to the acquisition of knowledge and the learning processes are introduced. Our starting point has been the Absorptive Capacity Theory (Cohen and Levinthal, 1990) and then we move through different visions of capabilities. The Natural Resource-Based View (Barney, 1991), the Dynamic Capabilities vision (Teece *et al*. 1997; Eisenhardt and Martin, 2000), as well as the Knowledge-Based View (Coombs and Bierly, 2006), all have contributed to build the conceptualization of firms' capabilities. Finally, our core approach focuses on the Technological Capabilities' (TCs) view that has been studied by two broad strands of the literature. One is the Technological Frontier Company literature (Prahalad and Hamel, 1990; Prahalad, 1993; Pavitt, 1991; Barney 2001; Helfat and Lieberman, 2002), and the other is the Latecomer Company Literature (LCL) of developing countries (Bell *et. al* 1982; Pack and Westphal, 1986; Dahlman *et. al*, 1987; Lall, 1987 Katz, 1997). Both contribute to build the understanding of firms' learning processes while also sharing many aspects with other previous theories.

However, the second TCs' strand seems particularly appropriate when describing firms' efforts in adaptive processes related to exploitation more frequently than with exploration (March, 1991). Many different categorizations of firms' TCs have been introduced along the years. One of them has been proposed by Sanjaya Lall in 1992 and regards the major technical functions involved: investments, production, and linkages capabilities. Thus, we select this taxonomy to help us disentangle firms' deliberate efforts in building TCs and in Part III of the present study we add to this taxonomy a fourth category that regards firms' strategies regarding strategic and organizational changes, with particular concern to the environment.

Under an evolutionary and systemic vision, this thesis focuses on the role of TCs as drivers of exports. Exports indicate the capacity to meet the specific needs of the international markets as well as the ability to respond to the changes and trends in such markets (Figueiredo, 2001). Consequently, exports entail a great stimulus as well as an important source of requirements of TCs, within a continuous technological change context. It is not easy to explain what happens first: if a firm build TCs because they export, or if they reach foreign markets because they already possess TCs. In this Part, we will be evaluating this reciprocal relationship.

In Part II, we analyze firms under a systemic vision and we consequently highlight the importance of linkages. Firms do not operate their TCs in isolation: they play in a dense network and interact through market transactions in their learning processes. There is a crucial need for cooperation between firms, suppliers, contractors, and clients, as well as research centers and universities in the way of catching up to the technological change. All these actors constitute what has been called the System of Innovation (Lundvall, 1988; Freeman, 1995; Malerba, 2004) analyzed from different perspectives: Sectoral Systems, Regional Systems, National Systems, etc. We prefer to analyze the commonalities of a Sectoral System of Innovation that allows us a dynamic and integrated view of sectors. We will be studying the agro-industrial system sector of innovation under its three "building blocks" (Malerba, 2002) and its relationship with innovation.

What makes innovation particularly interesting, when studying TCs, is that it not only represents the introduction of new products and new processes, but it reflects also firms' underpinning accumulation of knowledge and learning. Also regarding innovation, we look for the evolution of its concept. We present the conventional Schumpeterian Linear Model of Innovation, regarding the linear sequence that spans from R&D through innovation. Then, under a less simplistic vision, we recognize the complexity of the innovation phenomenon. R&D remains only one fundamental and necessary pillar that allows "recognizing" and exploiting new knowledge available in the system of innovation, but that needs to be complemented by the other TCs in the process of achieving innovation within firms (especially in developing countries). We also introduce another aspect of innovation: its spatial dimension. We evaluate the influence of firms' R&D investments within a spatial limited area (in our case the "Brazilian Units of Federation") in its neighbors' probability of introducing new products and new processes. The idea is that proximity can benefit from external knowledge flowing at different levels.

Many studies in literature have been attempting to predict why firms introduce new products and new processes, and if they follow a sequential or a simultaneous path.

To the traditional approaches we add our interest in understanding the role of R&D and the other TCs on product and process innovation. Also following a widely diffused literature, we evaluate the importance of some specific firms' patterns such as age, foreign ownership, and size. What makes these aspects particularly interesting is that there are some ambiguous behaviors concerning all of them. As a result, we can not anticipate if firms' specific patterns would exert positive influence over the propensity to innovate.

The research underlying this thesis also includes an empirical part, based on the World Bank Investment Climate Surveys and the Brazilian National Innovation Surveys. Different alternative TCs measures have been proposed along the years (Stuart and Podolny, 1996; Caffyn, 1997; Crespi and Katz, 1999; Battisti and Pietrobelli, 2000; Figueiredo 2001; Deeds, 2001; Wignaraja, 2002; Dutta et al. 2005) and we propose two different ways of measuring TCs: one is to construct a "Capability Score" that includes several firms' technical functions to proxy TCs. This score is based on the previously mentioned Lall's (1992) taxonomy to which we incorporate a fourth group that we call strategic capabilities (only (found in Part III of this thesis). The other way is a Principal Component Analysis (PC), that we use in Part II, to study the "agents" (knowledge base) building block within the Sectoral System of Innovation. Even if the two measures were used in different contexts, both of them bring us to the same conclusion about our studied firms' TCs' level: most of the firms in Argentina, Brazil, and Chile are investing only at basic levels.

Many criticisms have been raised against the use of a technology score to evaluate TCs, considering them as a shallow interpretation of reality and not able to follow firms' learning processes and capabilities' accumulation paths. The same can be said about the PC analysis. We accept that both measures have limits, but they deserve the recognition of allowing comparative analysis, albeit limiting the possibility of obtaining deep insights about firms' learning processes and their levels of capability accumulation. Instead, they give us the means to identify key clues for further specific research that could be fruitful when complemented by qualitative research and case studies.

As anticipated in the previous paragraphs, we are explicitly concerned about the influence of technological capabilities over exports and innovation. Three different approaches have been undertaken to cope with the main objective. The first, and the most general, regards the entire industrial sectors of Argentina, Brazil, and Chile. The second one focuses only on the agro industrial sector in the three countries, and the third one points only to the Brazilian case, giving only a brief insight into the fundamental importance of R&D and spatial R&D spillovers.

This thesis is organized in four parts. Part I provides a synthetic description of the evolution of technological development in Latin American countries. It follows an overview on the nature and determinants of technological capabilities and on alternative methods for measuring them. The first empirical analysis completes this part. Part II reviews the Sectoral Systems of Innovation focusing on their main building blocks. This analysis is applied to the agro-industrial sector, while another empirical study of the three countries is performed. Part III focuses only on Brazil, covering all the manufacturing sectors. The primary objectives are to underscore the relevant role of R&D as crucial TCs for achieving innovation, as well as to emphasize the role of R&D spatial spillovers on increasing the probability to innovate. Finally, Part IV outlines the conclusions of this thesis with suggestions for future research.

PART I: DRIVERS OF TECHNOLOGICAL CAPABILITIES IN DEVELOPING COUNTRIES: AN ECONOMETRIC ANALYSIS OF ARGENTINA, BRAZIL AND CHILE

1.1. Introduction

Latin American countries have shared similar patterns of industrial development over the last decades. At the beginning, gradual import substitution was the response to the growth of domestic markets and accounted for the establishment of industries with substantial locational advantages. During the 1940s and 1950s, import-substituting industrialization (ISI) was also a reaction to either low growth of income or to events beyond control (such as wars and depressions) and finally a matter of deliberate development policy. Most of the targeted “new industries” were in the consumer goods sector. As suggested in the Introductory chapter, firms produced in accordance with known processes and on the basis of imported inputs and machines, in a highly sequential, incremental and less learning-intensive way, expecting to supply only domestic markets (Hirschman, 1968). The 1950s and 1960s can be considered “the golden age” of the ISI model and were characterized by increasing demand for consumer and capital goods, with high tariff protection and subsidized financing for new production facilities. From the mid-1970s onwards, however, the growth process decelerated and some signs of revival in economic activity only appeared in the second half of the 1980s. The metal-working industries played a crucial role and starting from poor in-house capabilities, they improved their technological sophistication, accumulating engineering skills and developing a new organizational culture, albeit subject to many limitations (Benavente *et al*. 1997)

Trade liberalization and the deregulation of markets affected firms’ technological behaviours in these countries. In most of them, this happened after the 1990s generating the need for new production capacity, closer to the state of the art technology and the replacement of obsolete domestic technological capacities. Consequently “new learning paths” (Katz, 2001, pp.17) were needed. Different sectors were more or less prepared for the change: in some cases, some specific industrial policies helped firms to build technological capabilities and be prepared for international competition and the new economic conditions; in other cases, firms found market niches that allowed them to build expertise and capabilities more smoothly.

We will briefly introduce the evolution of industries in these countries, from the import substitution period to trade liberalization. This Part then explores the opportunities created for technological capabilities in the industrial sectors of Argentina, Brazil and Chile. The first two countries have been chosen because they are among the largest (first and third) manufacturers in Latin America and the Caribbean. Chile is Latin America's exceptional case of a fast-growing middle income country which balances active support with sound macroeconomic policies[1].

Along the whole dissertation, firms are studied under the evolutionary approach to the issues of technology in developing countries by assigning a central role to the need to exert indigenous technological efforts to master new technologies, adapt them to local conditions and improve upon them. It is well known that the process of mastering technology and accumulating capabilities is neither passive nor without cost. Thus, firms undertake the learning process in two senses: knowledge acquisition and knowledge conversion (Figueiredo, 2001). They perform technological efforts that may vary according to industry, size of firm or market, level of development, trade and industrial strategies pursued at the country level. Indeed, transfer requires learning because technologies are partly tacit and their underlying principles are not always clearly understood. Thus, simply to gain mastery of a new technology requires skills, effort and investment by the receiving firm and the extent of mastery achieved is uncertain and necessarily varies according to firm (Lall, 1992).

Furthermore, as argued in the Introductory chapter, we explore different approaches to explain how the learning process influences the paths of capabilities from the Absorptive Capacity (Cohen and Levinthal, 1990) theory, through the Resources-Based View (Barney, 1991), Dynamic Capabilities (Teece et al., 1997) theory, Knowledge-Based View (Leonard-Barton, 1995), focusing finally on the Technological Capabilities (TCs) approach at the firm level. With regard to Technological Capabilities, two main strands of literature are analysed: the Technology Frontier Company Literature (TFCL) and the Latecomer Company Literature (LCL). Both approaches are considered since they have been developed almost simultaneously and have influenced each other. Nevertheless, the core of our study will be mostly centred on Latecomer Companies and how firms undertake technological efforts and build capabilities.

The LCL evolved over the years and in the 1990s, most of these studies were focused on the descriptions of paths of TCs at industry and country levels while the

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[1] UNIDO, 2009.

relationship between paths and the learning process references was scarce (Figueiredo, 2001). More recent empirical LCL studies (Katz, 1997; Romijn, 1997; Pietrobelli, 1999; Wignaraja, 1998, 2002 and 2008a,b,c; Figueiredo, 2002, 2003 and 2008, Iammarino *et al*., 2008), on Technological Capabilities (TCs) in developing countries overcome these weaknesses. They draw on the evolutionary theory of technical change approach and concentrate on firms that cannot be assumed to operate on a common industry-wide production function. Then, inter-firm differences matter, suggesting the need for and importance of deeper analysis of inter-firm comparisons (Figueiredo, 2001).

Thus, since firms are intrinsically heterogeneous, technical skills are developed differently in each firm, depending on micro, meso and macroeconomic forces. The two latter forces influence firms' behaviour by depending on the enterprise's ability to change practices and absorb methods and technologies from the environment (Hoffman and Kaplinsky, 1989; Katz, 1997). Our analytical framework is thus centred on the concept of TCs to cover the issue of inter-firm and inter-country comparative analysis. We combine quantitative and qualitative elements and measure TCs on the basis of a modified version of Wignaraja's Technology Index (TI) at the firm level, presenting its weaknesses and strengths. Correlations between different firms' patterns and TCs, and between these patterns and exports, are analysed. Finally, an econometrical analysis is performed to check for the effects of factors such as foreign ownership, firm size, human capital and training on TCs and exports, based on the assumption that there is a reciprocal relationship between TCs and the firm's export performance.

1.2. Technological development in Latin America

In Latin America during Import Substitution Industrialization (ISI), the State, in conjunction with public banks and development agencies, designed large-scale production facilities (heavy industries and services such as telecommunications, water and sanitation), requiring significant amounts of TCs and expertise. For this purpose, they took responsibility for the development of human capital, for R&D investments through public labs and state-owned firms' engineering departments and for the design and the construction of many production facilities related to energy, communications services and other related activities. Meanwhile, private small and medium firms, as well as large ones, gradually developed their R&D departments providing themselves know-how and attempting to upgrade TCs (Katz, 2001). The former started using second-hand machinery but managed to train their workers to develop new processes and copy foreign products which were far behind the technological frontier. The latter carried out engineering efforts to adapt the generic machinery and equipment they purchased from foreign suppliers to the local raw materials and production environment. For this purpose, they set up engineering departments that provided "incremental units" of technical know-how but did not undertake efforts to develop complex TCs: they remained at elementary stages of processing locally available raw material (Katz, 2001). Thus, this process was not as impressive as the one observed in South Asian countries, but many firms developed technological skills that allowed them to improve competitiveness and productivity. This was the case with some metalworking industries (capital goods, consumer durables, agricultural equipment, transport equipment that includes automobiles) which, as skill-intensive industries, played a central role in developing in-house TCs, accumulating engineering skills, improving technological sophistication, controlling quality, and specially developing a mechanical, electrical, chemical and organizational "culture" (Benavente *et al.*, 1997).

Nevertheless, high tariff protection, a lack of competence, weakness in the organization of factories and excess of demand, prevented the development of complex TCs within these firms. In this context, competitiveness was difficult in the late 1970s and in the early 1980s when more sophisticated capital goods and consumer durables were required and when 'flexible manufacturing' organizational principles became the 'best practice" of industrial firms (Benavente *et.al*, 1997). There was a second phase in the ISI strategy. Argentina and Brazil decided to intensify their strategies by subsidizing "state of the art" raw material processing industries (pulp and paper, steel, petrochemical, vegetable oil, etc). Chile preferred to subsidize only natural resource-based industries (pulp, paper, fishmeal, etc.) between the 1960s and the 1970s and to open up the economy to external competition. Both strategies allowed a rapid expansion of exports in these sectors. By contrast, the metal-working sectors lost their share of exports in three countries. However, in Argentina and Brazil, there was a recovery in this sector after the 1990s (Benavente *et al*, 1997).

When the region moved towards trade liberalization and market deregulation, state-owned and industrial firms changed their production strategy. The state-owned firms were replaced by large international firms which introduced updated imported equipment, reducing the technological gap between Latin America and developed countries. Most of the private industrial firms substituted locally produced equipment as well as domestic parts and components, relying mostly on imported technology that was both cheaper and nearer to the technological frontier. This process went beyond a simple factor substitution due to price change: it involved changing patterns of technological behaviour and discontinuing many local engineering and R&D activities.

Among the most affected industries, there were the metal-working and capital goods which found it difficult to compete in domestic and export markets after liberalization. Nevertheless, Brazilian firms in this sector were the exception: their technological maturity, larger domestic market and the longer and deeper support received from the government during the ISI period, explained why firms had more TCs as instruments to face trade liberalization in this country (Benavente *et al.*, 1997). In Argentina, the steel industry had already undergone restructuring processes and transnationalization changes in the 1980s. The state-owned enterprise was acquired and rehabilitated as one of the two large locally owned conglomerates that became a “global player”. Thus, there were not only births and deaths of enterprises, but also different industrial behaviours that implied new ways of training workers, world-class R&D infrastructures, younger and more professionalized business management and more connections with the foreign environment (Katz and Stumpo, 2001).

The new production model damaged some domestic capabilities and the process of technological upgrading was slow, difficult and fragmented (Katz, 2001). These circumstances, added to the extreme uncertainty and instability of the macroeconomic framework, hindered the process of innovation and industrial development in Latin America. Cimoli and Katz (2002) describe the 1970-2000 period in Latin America using the Schumpeterian metaphor of “creative destruction”. The new regime caused some enterprises to disappear, accompanied by changes in trade and market behaviour as well as other structural changes. The macro slant, highlighted by the huge impact on the meso and micro phenomena, showed that the three aspects evolved together and in an interrelated way.

As stated before, the patterns of production changed at least in two ways after trade liberalization. Some firms changed the high degree of vertical integration of the 1970s since it was no longer profitable, invested in new equipment and retrained production workers. Others acted defensively, saving labour without commitment to new production capacity (Benavente *et al.*, 1997) and without performing adaptative changes. Firms' decisions have been quite different in facing these changes. Indeed the coexistence of this heterogeneity influenced, on the one hand, the dynamics and structure of industries and, on the other, the chances of advances for the whole industry (Bisang *et al*., 1996).

After the 1990 reforms, the dominant production and trade specialization model moved towards the processing of natural resources to produce industrial commodities in the countries studied here (Katz and Stumpo, 2001). In some cases, they involved investment in highly automated plants; in others, expenditures in R&D and technology, coming from foreign countries which usually resulted in few technological efforts and the building of only basic TCs.

Industries producing "wage goods" founded on unskilled labour such as footwear, textiles and furniture, did not have the necessary TCs to compete with foreign competitors arriving on their domestic market and lost importance particularly in Argentina. The same happened for industries producing capital goods, agricultural equipment and other engineering-intensive activities that needed more complex TCs such as R&D and engineering services in Chile. These activities faced a massive increase in competition facilitated by trade openness. However, trade liberalization sometimes also involved a fall in input tariffs that could give access to foreign inputs (Katz and Stumpo, 2001). In some cases, adaptative TCs were still needed while in others, due to standardized products, the local firms only became assemblers of foreign inputs and lost their domestic TCs.

However, new opportunities to build TCs were created in particular cases such as enterprises in the fastest growing industries like computer science, software, and other new fields (Katz, 2001). Indeed, after the opening up of the economy and the transition to a computer-based technological frontier, firms working in these sectors were able to benefit from linkages with foreign partners, both buyers and suppliers.

Through highly subsidized policy, the motor industry in Argentina built TCs by making strong investment efforts in new equipment. In Brazil, the State supported the aircraft industry which made important improvements in TCs serving as the basis for its present export success (Goldstein, 2000). The latter case suggests that industrial policy has been crucial in helping to develop TCs in some sectors. The State was also involved in substantial R&D investment. However, industrial performance still reflects the insufficient R&D efforts in these countries. Thus, for example, while the OECD's R&D investments decade-average during 1960-2000 fluctuated between 1.87% and 2.25%, Latin America only fluctuated between 0.36% and 0.52% of GDP. In recent years, Chilean R&D expenditure has reached 0.6% of GDP, still below Brazil's 0.84% but above the 0.52% regional average. Also, with regard to patents, Latin America was still lagging behind most of the developed world with an average of 258 patents per year during the period 2000-04 (Australia alone was at 858).

A final remark is that, in almost all sectors, firms that were not prepared to face external and technological advanced competition because of their lack of TCs were the ones that suffered most from external competition. Nevertheless, some firms kept on investing and performing indigenous efforts but in many cases this have not been enough since mesoeconomic factors and macroeconomic uncertainty have also hampered their TC development.

1.3. Nature and determinants of TCs

We will now focus on how firms' efforts help them to deal with technological change. They undertake a "learning process" that can be defined in two different senses: the first refers to the path along which the accumulation of technological capability proceeds (knowledge acquisition process), the second one refers to the processes by which individual learning is converted into organisational learning, allowing firms to accumulate capabilities over a period of time (knowledge conversion process) (Figueiredo, 2001 and 2002). Analysing the second sense, it has two important elements that are closely interrelated: an existing knowledge base and intensity of effort (Cohen and Levinthal, 1990). The former contributes to strengthening the latter through the spiral process of technology learning. Education, skills and quality enhance people's ability to receive, decode and understand information: process and interpretation are important for performing or learning how to perform many jobs (Nelson and Phelps, 1966).

The learning process is based on the assumption that firms need to have "prior knowledge" that allows them to "recognize" the value of technological change available in the system of innovation and to assimilate and exploit new knowledge. These abilities constitute Absorptive Capacity (AC) (Cohen and Levinthal, 1990) which is enterprise specific and becomes a critical component for technological change since it cannot be bought or quickly integrated into the firm. This approach remains a shared and indisputable basis for all the other capability approaches and is based on the fact that investments in R&D anticipate the future development of a technical capability within the firm.

Expanding knowledge bases and AC are also crucial for sourcing sustained comparative advantage: only through experience and learning, firms achieve high rates of return and superior firm performance (Dierickx and Cool, 1989; Nelson, 1991; Barney, 1991; Barney, 2001; Coombs and Bierly, 2006). In spite of focusing only on R&D, the Resource-Based View (RBV) approach (Barney, 1991) introduces the concept of sustained competitive advantage which is almost contemporary to the AC vision that derives from firms' resources and capabilities which are valuable and rare and neither perfectly imitable nor substitutable.

Thus, resources and capabilities are closely interlinked (Barney *et al.*, 2001). The Dynamic Capabilities[2] (DC) vision enhances and complements the RBV approach particularly by extending it to dynamic markets and changing environments (Teece *et al*. 1997). DC are idiosyncratic, experiential, unstable processes that rely on quickly created new knowledge and iterative execution to produce adaptive and unpredictable outcomes that are difficult to sustain most of the time. Firms use these processes to alter their "resource base" and create competitive advantage. Learning mechanisms (routines) and path dependence guide the evolution of DC (Eisenhardt and Martin, 2000).

The Knowledge-Based View (KBV) of the firm is an extension of both RBV and DC under the assumption that knowledge is the fundamental resource of the organization. The distinction between individual, group and organizational knowledge is another important issue in this theory and the development of technological capabilities is one of its main strategies as a source of competitive advantage (Coombs and Bierly, 2006). The "common ground" of these streams of literature is the need for resources (physical, human and organizational), the process of learning and the need for flexibility to adapt to changing environment. Our last and core approach for this study

[2] DC are defined as the competences which allow the firm to create new products and processes and respond to changing market circumstances (Teece and Pisano, 1994).

regards Technological Capabilities (TCs). The issues of TC building and the underlying learning processes have been addressed in two bodies of literature: one is the Technological Frontier Company literature[3] (TFCL) and the other is the Latecomer Company Literature (LCL) of developing countries[4]. They both agree on the fact that firms follow different paths of TC accumulation associated with different performances (Figueiredo, 2002).

The first one (TFCL) refers to technological frontier companies. The characteristics of technical change in market economies have led to the development of evolutionary theories of technical change, emphasizing the central importance of dynamic competition through continuous innovation and imitation, together with disequilibria, uncertainty, learning, and inter-firm and inter-country differences in competencies and behaviour (Nelson and Winter, 1982; Dosi, 1988; Bell and Pavitt, 1993). Their "knowledge base" includes inputs, knowledge and capabilities that inventors draw on to innovate (Dosi, 1988). Their processes of learning enable them to increase their competences as a result of experience, monitor the external environment and assimilate radical technologies and corporate learning (Pavitt, 1991). These companies expected to create "new competitive space" throughout the whole organization under the crucial leadership of managers (Prahalad, 1993). These companies, as adopters or users of diffusing technology already possess knowledge and skills needed to play a creative role (Bell and Pavitt, 1993) and "core" technological knowledge is required to create a product or a service while "complementary" capabilities are needed to profit from technological knowledge (Helfat and Lieberman, 2002). The real sources of advantage are to be found in management's ability to consolidate corporate technologies and production skills into competencies that adapt to changing opportunities (Prahalad and Hamel, 1990).

The second one (LCL) explains, for instance, how acquiring foreign technology can contribute to building up a stock of proprietary technology and firm specific know-how (Katz, 198). It shares many aspects which are similar to the previous visions and is conceived as the ability and efforts of firms, changing over time according to technology advances to make effective use of technological knowledge (Westphal *et al*. 1985). In emerging countries, the starting point in technological development is

[3] Prahalad and Hamel, 1990; Prahalad, 1993; Pavitt, 1991; Barney 2001; Helfat and Lieberman, 2002.
[4] Bell *et.al* 1982; Pack and Westphal, 1986; Dahlman *et. al*, 1987; Katz, 1997; Lall, 1987; Romijn, 1997; Pietrobelli, 1999; Wignaraja, 1998, 2002 and 2008a,b,c; Figueiredo, 2002, 2005 and 2008, Iammarino *et al*., 2008.

different: firms need competences for improving or adapting technology to local conditions. Adaptive processes are mostly needed and this means that exploitation is more frequent than exploration[5] (March, 1991). TCs therefore represent the ability to employ existing technology, absorb the descriptions, comprehend the explanations and follow the procedures (Enos, 1991, pp.167) including organizational aspects (Figueiredo, 2001). The incremental change is the common pattern and only in some limited cases, firms achieve "domestically-generated" technical knowledge (Katz, 1984).

1.4. Alternative methods for measuring TCs

1.4.1. The Technological Frontier Company Literature

There have been various attempts to measure TCs. Figueiredo (2001) pointed out some of the strengths and weaknesses of these studies in the literature. The strengths are that this literature explores in great detail the organizational and managerial dimensions of TCs and their influence on process and product innovation and competitive advantage, as well as the learning process underlying TC building. The weaknesses include the fact that little attention is given to the way in which innovative activities, already available in the world, are undertaken within companies.

Some examples of TFCL measurement of TCs are presented here. Voss (1988), as an extension of life-cycle literature, studied management literature's interest in the problems of getting Advanced Manufacturing technology to work. He constructed a subjective but consistent indicator: the identification of all articles on technology implementation in the issues of the Production and Inventory Management Journal from 1972 to 1983. He also studied 14 advanced technology innovations in the U.S., U.K. and Australia and found that, despite all of them being a technical success, a significant number failed to improve competitiveness.

The "learning curves" have been another way of studying how technological change can evolve in each adopting firm, such as, for instance, the importance of "Continuous Improving" (CI) in Japanese firm competitiveness (Imai, 1986). Prahalad and Hamel

[5] "The essence of exploitation is the refinement and extension of existing competences, technologies, and paradigms. Its returns are positive, proximate, and predictable." (March, 1991, pp. 85).

(1990) compared different firm strategies (NEC, GTE, Sony, 3M, etc) highlighting the importance of “Core Competences” to coordinate production skills and integrate multiple technologies. Schroeder and Robinson (1991) presented a comparative analysis of U.S. and Japanese case studies underlying the crucial role of cultural factor and environment in the successful implementation of CI. Leonard-Barton (1992), by adopting a knowledge-based view of the firm, studied 20 new products and new process development projects in 5 companies in the U.S. She concentrated on their interaction with capabilities along the time, according to the alignment of values, skills, managerial and technical systems required by the project. Caffyn (1997) identified levels of CI capability in 70 U.K. companies representing different industries. She observed that firms moved through these levels of CI by building core abilities and key behaviours, especially if a significant proportion of the organization is involved in innovation.

In the 1990s, studies started to focus on leading companies increasing expenditures on R&D (often larger than expenditures on fixed capital), as well as expenditures on raising the skills and the knowledge of human resources. The weakness of these types of measures had been underlined by Bell and Pavitt (1993, p. 167): “measured R&D activities are only the tip of the iceberg, since they are a form of accumulation typical of large firms in science-based technologies. In smaller firms, technological activities are sometimes part time and sometimes given other names like 'design' and 'production engineering'”. A variety of patent statistics and measures of R&D intensity have often been used as indicators for TCs. Within this strand of literature, Deeds (2001) focused on 80 pharmaceutical biotechnology companies to analyse the relationship between R&D, technical capabilities and absorptive capacity. The basic idea was that TCs are created by investing in R&D and then, if firms develop technical capabilities, they turn basic research into patents or new products. He used R&D expenditures to proxy TCs; patent applications, patents and products in the various stages to proxy technical capabilities and co-citation analysis of the bibliography where firms’ scientists and engineers participate to indicate absorptive capacity. He concluded that R&D investments are fundamental in complex technology. Dutta et al. (2005) estimated R&D capabilities and the stochastic frontier to infer capabilities of firms in the semiconductor and computer equipment industries.

They underscored the heterogeneity in R&D capability across firms in this industry. This involves a citation analysis of over 10,000 patents issued to various firms.

Other studies concentrated on patent citations. Stuart and Podolny (1996) stressed that in-depth case studies of individual organizations or industries allow organizational learning and technological evolution to be described. The difficulty is that they are not suitable for a systematic assessment of interfirm, intertemporal or interindustry variance in the research. They then developed a methodology in which inventions of a group of competing firms served as a reference point for identifying technological shifts of individual members. Given that patent citations identify the technological antecedents of a firm's current inventions, they used them to map the technological position of the largest firms in the Japanese semiconductor industry across different periods, concluding that firms' positions derived from skills that were difficult for competitors to replicate quickly.

Coombs and Bierly (2006) recognized that there was a set of studies that use R&D expenditures, patents, or a combination of both of them, as indicators of TCs. Most of these measures covered only partially TCs and different measures were leading to different results that needed to be carefully interpreted. R&D spending and patents were usually not valid measures of TCs. R&D investments, on the one hand, were not always formally measured and, on the other hand, firms experimented and developed new products and processes that did not necessarily lead them to achieve TCs. With regard to patents, not all TCs were patentable and in some cases, firms decided not to patent and to keep their new ideas secret. When analysing patent citation, there was a potential problem: although they allowed researchers to trace the development of innovation over a period of time, some firms were not interested in listing their external knowledge sources if they came from their competitors. After exploring all these difficulties, Coombs and Bierly (2006) studied the relationship between TCs and firms’ performance in 201 large US public manufacturing companies, using different patent statistics and R&D intensity. Based on this information, different measures (returns on assets, returns on equity, returns on sales, market value, market value added and economic value added) were explored under the assumption that there was a lagged and positive relationship between TCs and firms’ performance.

Finally, Figueiredo (2001) pointed out that few studies explored day-to-day manufacturing operations. The weaknesses in these cases have been that they did not investigate how firms differ in the way they build, use and accumulate capabilities. Others studies focused on how individual learning is converted into organizational learning. They are rich in the specification of learning processes although they do not follow their paths over a period of time. Sophisticated and multiple measures of TCs that include aspects like technology flow, organizational aspects, etc., are superior to others based on counting patents or R&D expenditure since these could be misleading.

1.4.2. The Latecomer Company Literature

In the second strand of literature, since 1970 some studies performed in Latin American countries have focused on steel plants with a number of merits including uncovering learning mechanisms underlying the accumulation of TCs in those plants, highlighting the significance of in-house efforts to promote the process of technical knowledge generation to create TCs and also enhancing the fact that the accumulation of TCs is a necessary condition for technical change. The weaknesses were that these studies focused on individual plants avoiding a comparative analysis and also that they did not explore the process by which individual learning is converted into organizational learning (Figueiredo, 2001). For instance, rayon plants were studied in Argentina (Katz et al. 1978), and the same problems as reliable generalizations were encountered since no comparisons were made with firms producing similar products (Figueiredo, 2001).

Some years later, both weakness were overcome in different studies. With regard to the first one, the challenge of measuring inter-firm differences in TCs has been addressed by authors like Crespi and Katz (1999) who studied the accumulation of knowledge in Chilean manufacturing industry. Battisti and Pietrobelli (2000) performed empirical analysis based on a sample of 338 industrial enterprises from Chile, studying firms with different levels of technological complexity. Figueiredo (2008) studied TC building based on 46 firms in the Brazilian industrial pole of Manaus, concluding that policies and factors at the meso and micro level matter for understanding learning strategies underlying firms' TCs. On the basis of one of Lall's taxonomies, he distinguished between "routine" production capability and "innovative" TCs. In this study, he focused specifically on two groups of firms: electro-electronic firms and suppliers, and bicycle and motorcycle firms and suppliers. He measured TCs according to the type of activity (process) a firm was able to do on its own, at different points in time, identifying not only the manner and level of difficulty, but also the time scale that each firm needed to reach a higher capability level. He then introduced another important issue, the "time" needed for capability accumulation.

As far as the second weakness regarding TCs studies is concerned, it has been settled in studies like Katz's (1980) where he pointed to issues like production organization systems as critical for understanding domestic TCs. Bessant and Kaplinsky (1995) also studied industries in the Dominican Republic and the effects of the government policy reforms shown on the restructuring programme. The reforms implied the introduction of organizational changes at various levels of industrial activities (individual firms, relationships between firms and between firms and the state institutions). Dutrenit (2000) also provided interesting findings on the need for organizational learning. Focusing on Mexican glass companies, she found that their uneven learning process was in part due to the limited efforts to convert knowledge from the individual to the organizational level (Figueiredo, 2001).

When also considering organizational learning aspects, Humphrey (1995) analysed the ability of developing countries to adopt Just in Time (JIT) or Total Quality Management (TQM) principles. He observed that both principles had been used by a wide range of firms in many developing countries including Brazil, Mexico, Korea, Zimbabwe and the Dominican Republic. The results of the appropriation of these principles have been different with regard to the acquisition of TCs and competitiveness depending on the depth and effectiveness of their adoption, the size of the firm and the technological sophistication of the sector.

Figueiredo (2001) also highlighted another limitation of some TC studies in different developing countries: they rarely mentioned the "learning mechanism"[6], treating organizational practices as given mechanisms. Under a wider view and by performing quantitative analysis, Romijn (1997) developed satisfactory and objective measures

[6] The previously mentioned Figueiredo's study (2008) of the industrial pole of Manaus overcame this weakness: he analyzed firms' learning strategies underlying firms' TCs building and supporting organizations.

for evaluating TCs and their underlying learning process for Pakistan, using both information about intra-firm activities as well as information on the interaction of the firms with the environment. She focused on production capabilities in small firms and proposed a production capability indicator to capture the manufacturing complexity of products as a proxy for the level of production capability embodied in each product. She distinguished between "in-house" manufacturing and "vendor operations" (subcontracted to other firms). She also ran cross-section regressions to conclude that general education level, technical education, the availability of technical support services, firm size, information search and product improvement were all relevant explanatory variables. Firms' technological efforts to assimilate and improve technology and human capital formation also proved to be very important for building TCs.

There has been an important trade-off in the selection of methodology for analysing TCs in LDC. On the one hand, some qualitative case studies have given deep insights into TC accumulation, learning process and the transformation of individual into organizational knowledge without obtaining important comparative conclusions. On the other hand, quantitative inter-firm analyses have highlighted some interesting findings on a specific industrial sector or in other cases, different sectors, albeit in some cases, losing the paths of TC accumulation and the organizational aspects of TCs.

With regard to quantitative studies, Costa and Robles Reis de Queiroz (2002) proposed a quantitative method to compute TC proxies. It involved an analysis of TC classification and the distinction between generation and use of knowledge on the basis of Brazilian innovation surveys database focusing on the role played by foreign owned companies in technological learning. Wignaraja (2002, 2008a,b,c) also contributed with important empirical work, following the pioneering studies of Westphal *et al.* (1990) on Thailand and Gonsen (1998) on Mexico. TC scores were performed with the aim of placing objective and subjective capabilities' information into indices. The objective was to reflect the firms' efforts to acquire, adapt and improve technology in an uniform and aggregate way (Westphal *et. al*, 1990). It was therefore advisable to identify the most distinctive elements of firm TCs to assign them values that enabled them to be ranked (Gonsen, 1998). He did this and also analysed TC determinants, creating an enterprise score as a summary measure of capabilities by selecting technical functions regarding investments, production and linkage activities performed by the firms in developing countries to manage imported technology. He assigned each enterprise a score for each technical function and also indicated its level of competence. These scores were gathered in an overall capability score called "Technology Index" (TI) and the influence of specific firms' characteristics was explored. Iammarino *et al.* (2008) also examined an index of TCs which associated firm-level factors in the electronic industry in two Mexican regions, combining analysis at micro and meso levels.

For the purpose of this Part, we were particularly interested in the relationship between exports and TCs. Figueiredo (2008, pp.74) argued that "…as exporting firms are more exposed to specific needs of the international markets they supply, they need to respond quickly to and/or anticipate the changes and trends in such markets. This, in turn, appears to be reflected on the speed at which they adapt and upgrade their process and production organization capabilities to meet new requirements of product design. This further suggests that exposure to foreign competition is relevant for firms' innovative capability building". TCs are then expected to be positively related to export performance although the direction of causality can be both ways. The process of acquiring TCs implies improving and creating experience and skills that are dramatically important for exporting. In turn, however, exports provide incentives and opportunities for creating TCs and open the way to useful learning opportunities. Several studies have explored the link between TCs and export performance. For instance, van Biesebroeck (2003), for nine African countries, confirms that export manufacturers in Sub-Saharan Africa have a higher level of productivity than non-exporters, but also that exporters increase their productivity advantage after they start exporting. Alvarez and Lopez (2005), for Chilean manufacturers, based on the Annual National Industrial Survey, introduce the hypothesis that the presence of a "conscious self-selection process" is what induces some firms to adopt new technologies and to increase productivity with the explicit purpose of becoming exporters.

Our analysis is based on both literature approaches of TCs under the Bell and Pavitt (1993) definition of TCs: "the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages". Firms' asymmetries may be explained by Technological Capabilities (TCs) as one intra-firm crucial factor for enterprises' success. These capabilities need to be dynamic in order to adapt and change properly while the environment evolves. They embody the resources and organizational structures required to acquire technology from outside, modify it to local conditions, if necessary, and possibly improve it in order to manage the technical change.

We are aware of the importance of exploring changes in the industrial organization of firms in order to understand inter-firm differences. Nevertheless, our analysis is constrained to only one comparable data item for different sectors in these countries. Within this context, we focus our attention on the firm as a unit of observation. In-house technological efforts are essential to firms' performance and contribute to creating investment, production and linkage capabilities as suggested by Lall's taxonomy[7] and described in the following paragraphs:

Investment capabilities are the skills, knowledge and organization needed to identify, prepare and obtain technology to design, construct and equip an expansion or a new facility. They include capital costs of the project, the selected technology and equipment and the understanding gained by the operating firm of the basic technology involved.

Production capabilities start from the last step of the first typology: basic technology skills such as quality control, operation and maintenance, to more advanced ones such as improvement or adaptation to research, design and innovation. This implies technology mastery and, in others, minor or major innovation.

Linkage capabilities are the skills, knowledge and organization needed to transmit information, skills and technology to receive knowledge from component or raw material suppliers, consultants, service firms and technology institutions. They also include access to external technical information and support (from foreign technology sources, local firms and consultants and the technology infrastructure of laboratories, testing facilities, standards institutions and so on) and access to appropriate "embodied" technology in the form of capital goods from the best available sources, domestic or foreign.

Since we are working with information for one year, our first caveat regards the fact that this Part of the study is limited to knowledge acquisition only and processes of knowledge conversion are not explored. We also assume, particularly when considering developing countries, that most of the firms that are analysed only

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[7] "The Lall taxonomy of technological capabilities has been successfully used by case study research to assess levels of firm-level technological development in developing countries (for a selection see Lall, 1987; Lall, Barba-Navaretti, Teitel, and Wignaraja, 1994; Wignaraja, 1998; and Romijn, 1997). Subsequently, a technology index (TI) based on the Lall taxonomy (or its variants) has been developed for econometric testing, in several developing countries (see, for instance, Westphal et al. 1990; Romijn, 1997; Wignaraja 1998, 2002, and 2008b and 2008c; and Wignaraja 2008a, Appendix I, p. 14)

perform exploitation of “old certainties” in knowledge learning (March, 1991). Then, this process of knowledge acquisition implies that a basic core of functions needs to be internalized by the firm and contribute to incremental TCs. Although the concept of TCs is highly qualitative and is very difficult to measure in absolute terms (Gonsen, 1998), we propose a quantitative-qualitative score of these technical functions at a certain point in time, using the Lall’s taxonomy presented below to compute a modified version of Wignaraja’s Technology Index (2002, 2008a,b,c).

1.5. The model

Our research topic concentrates on the determinants of TCs and argues that firm size, foreign ownership, years of experience in the specific sector, skilled trained production workers, leader’s experience in the sector and exports are crucial to firms’ TCs. The rationale for these hypotheses is explained below. The first part of our theoretical model therefore takes the following form:

$$TI_i = f\,(Sz_i, FE_i, Age_i, SkTrPr_i, Edu, MgEx_i, Exp_i) \qquad \text{(I)}$$

where TI is a modified version of Wignaraja’s[8] Technology Index, calculated as a comprehensive score for firm *i*. It is expected to be a function of different patterns: *Sz* is the firm’s size, *FE* is the firm’s foreign ownership, *Age* considers the firm’s years of experience, *SkTrPr* refers to the firm’s skilled trained production workers, *Edu* is the level of education, *MgEx* is related to the firm’s manager experience and *Exp* means exports.

TI highlights the various technical functions performed by enterprises. To construct TI, a score for each activity, based on the firms’ level of competence in that activity, is obtained and finally, an overall score of firms’ TCs is reached (Wignaraja, 2002). The TI’s main strength is that it is a simple and practical way of comparing inter-firm differences in capabilities. The basic idea is “the attempt of a qualification, however tentative or cautious, of firm level technological behaviour” (Lall and Latsch, 1999,

[8] Wignaraja (1998b) tested an overall Technology Index (TI) and also a production TI, against firm-level characteristics (size, foreign equity, technical manpower, and technology imports) for a sample of 27 garment and engineering enterprises in Sri Lanka. After that, in 1999 he worked with Ikiara on the TI for Kenyan enterprises. In 2002, he tested the TI with Mauritius enterprises and, in 2008, TI in Sri Lanka clothing exports.

p.52). One of TI weaknesses regards the score's difficulties to communicate their meanings: they should be carefully analysed to produce useful information for comparative analysis. TI is "a convenient shorthand summary rather than a comprehensive indicator and represents an instrument to be deployed in quantitative and statistical analysis. Such quantitative analysis, however, cannot entirely replace a more detailed case-study approach" (Lall and Latsch, 1999, p. 52). Another difficulty is that the TI is highly dependent on the nature of the technology and needs detailed information on it (Gonsen, 1998). Consequently, our second caveat is related to this aspect: we perform a whole manufacturing sector analysis for each country, using the type of technical functions that can be comparable, independently from the underlying particular technology, and without deepening its level of complexity and cumulativeness. The reason for selecting to work with overall scores is that, as technologies are becoming more sophisticated in all industrial sectors, technology adaptation is essential to any industry (Kritayakirana and Srichandr, 1989). Our selected TCs are expected to be present in the whole industrial sector and to become a comparable basis. They then allow us to make this type of analysis, expecting a high level of conformability and comparability of scores within each country and through cross-country comparisons (Lall and Latsch, 1999).

When considering the determinants of TCs, we include firm size (Sz). This is expected to exert a positive relationship with TCs since returns from capability acquisition are expected to be higher for larger firms that can spread their related fixed costs better (Wignaraja, 2002). However, Deraniyagala and Semboja (1999) found that the effects of size are sometimes ambiguous: positive effects related to scale economies and the availability of resources to invest in skills and technology can coexist with negative effects. The latter may come from the lack of supervision and the existence of management difficulties. Iammarino et al. (2008) also highlight size unpredictability: sometimes, product-center capabilities can be found in small and medium size firms rather than in large firms.

The effects of foreign ownership (FE) on TCs partly depend on the type of relationship between the foreign and host companies: on the one hand, it is important to evaluate how much foreign affiliates have privileged access to the ownership advantages (technologies, skills and marketing know-how) of their parent companies (Girvan and Marcelle, 1990; Wignaraja, 2002); on the other hand, it is also crucial how deep the existing TCs are within the host firms so that they can absorb foreign knowledge better. Both issues finally influence what Costa and Marin (2007) point out: the technological learning process that takes place in the host firms. Then, the effects of (FE) on TCs are not easily predictable and may be different, depending on the mentioned patterns.

The Age variable can also exert different consequences over TCs. Since learning is not an automatic process that occurs with the passage of time, the way in which firms organize their learning process is critical to the building of TCs. Experience appears to be very important demonstrating the importance of “learning by doing”. This variable is then positively related to TCs only if there has been knowledge acquisition and TC accumulation paths within the firms over the years.

With regard to the variables Edu and SkTr, technical manpower and training expenditures should be positively related to the TCs, suggesting that investments in human capital improve technological performance (Wignaraja and Ikiara, 1999; Wignaraja, 2002). As stated by Figueiredo (2002), it is the internal knowledge-acquisition process that allows individuals to acquire knowledge by doing different activities inside the company. Consequently, an endowment of highly qualified human resources is not a capability per se, but a resource that, through learning and training, may become a source of TCs for the firm (Iammarino *et al.*, 2009). The importance of training for TCs has been widely recognized (Katz, 1984; Kritayakirana and Srichandr, 1989; Girvan and Marcelle, 1990; Bell and Pavitt, 1993; Lall, 1994(b); Dutrenit, 2000; Figueiredo, 2001 and 2008; Wignaraja, 2002 and 2008a,b,c). However, the level of its influence is related to decisions such as in-house or outside industrial firms (Bell and Pavitt, 1993) and to the type of training, for instance, higher education or specialized training for specific technology (Lall, 1992). Then, both variables need to be contextualized to understand their effect on TCs.

Leadership and management experience reflected in our variable MgEx, can be positively related to TCs when skillful managers are able to deal with technological change. Indeed Girvan and Marcelle (1990) put management as a crucial factor which, in some cases, is more important than technology sophistication. Nevertheless Figueiredo (2001, 2008) remembers that managers may also limit in-house efforts to build TCs. The effects of this variable on TCs should therefore be carefully analysed.

With regard to the influence of the Exp variable on TCs, foreign competitive pressures tend to lead firms into technological efforts (Katz, 1984). Access to foreign markets is frequently important stimulus and pressure for increasing and accumulating TCs (Kritayakirana and Srichandr, 1989; Bell and Pavitt, 1993). Thus, this variable is expected to exert a positive impact on TCs . The magnitude of this relationship will depend on the type of market and the skills and technology composition of the exports.

The second part of our theoretical model regards the relationship between the following variables and exports:

$$Ex_i = f\,(Sz_i, FE_i, Qual_i, Age_i, Edu, SkTr_i, TchFe_i, InpFo_i, R\&D_i) \qquad \text{(II)}$$

where Ex are the exports of firm *i* and are expected to be a function of different patterns: *Sz* is the firm's size, *FE* is the firm's foreign ownership, *Age* considers the firm's years of experience, *Edu* refers to the level of education, *SkTr* refers to the firm's skilled trained production workers, *TchFe* is the reception of technology from foreign firms, *InpFe* means the use of foreign inputs and *R&D* represents R&D investments.

The variable Sz is expected to be positively related to exports. Indeed, economies of scales are frequently needed for exporting (Katz, 1984). Nevertheless, this variable can be irrelevant to exporting when some of the critical issues for small firms, such as financial and technology access, are overcome by creating joint-ventures or by the fact that they are foreign owned.

With regard to the FE variable, it can also represent easy access to external markets. Indeed, export success is sometimes linked to the ability to attract more and better foreign direct investments (Lall, 2000). From some empirical studies, the share of foreign equity is expected to have a positive influence on the probability of exporting (Wignaraja, 2008).

The Qual variable also has frequently positive correlations with exports: obtaining quality certification can be an important push to reach external markets (Lall, 2000). There is not only one type of certification that guarantees access to external markets, indeed, different types of quality certifications are frequently needed to reach external markets (Figueiredo, 2008).

With regard to the firms' age, its relationship with exports depends on the specific case. Sometimes younger firms are more likely to begin to export, suggesting that they start operations with the international markets in mind (Alvarez and Lopez, 2005). In other cases, firms' experience in the field can allow them to easily access external markets.

Several studies confirmed that Edu and SkTr have positive impacts on Export Share (Pietrobelli, 1999; Kim, 2000). We therefore expect a positive association between these two variables with exports (Bernard and Jensen, 2004).

Technology received from foreign suppliers, both in embodied technology as inputs (InpFo) or unembodied technology as licenses (TchFe) should also be positively associated with exports. In some cases, firms that spend more on foreign licences are more likely to enter export markets (Alvarez and Lopez, 2005). This is particularly true in firms that lack best practices: exporters produce at different technology levels than non-exporters (van Biesebroeck, 2003).

The *R&D* variable is expected to have a positive relationship with exports. Firms have to undertake conscious investments in search, engineering and R&D to reach the foreign markets (Lall, 1987; Alvarez and Lopez, 2005; Wignaraja, 2008).

The third part of our model brings together the first two equations. The acquisition of TCs, reflected in our model through TI, is seen as a major source of export advantage at the firm level (Wignaraja, 2008). Exporters also acquire information from foreign customers who may suggest ways to improve the manufacturing process, product design and the quality of the goods that are reflected in increasing TCs (Alvarez and Lopez, 2005). Drawing on the rich literature of Wagner (2007), Bernard and Jensen (1999) and Bernard and Wagner (1997), as well as other authors, we introduce the effects on TCs of firms' access to external market in our model in order to check if there is a mutual relationship between TCs and exports. This theoretical approach investigates the export activity of firms and its causes and consequences. These authors deepen into two not mutually exclusive hypotheses on why exporters may be more productive than non-exporter firms. The first hypothesis is that the self-selection process moves more productive firms into export markets and the second one underlines the role of learning by exporting in fostering productivity. However, it is important to ask whether good firms become exporters or whether exporting improves firm performance (Bernard and Jensen, 1999). Then, it could be a circular self-reinforcing process, in other words, the problem of the direction of causality remains unsettled.

By developing this framework, equations (I) and (II) allow us to specify the econometric empirical simultaneous equation model where our dependent variables, TI and EXP, are jointly determined. We work with the following exogenous variables selected on the basis of their influence on the process of building TCs and increasing the probability to export. On the identification issue, at least one exogenous variable appearing in one equation does not appear in the other equation (Keshk, 2003) and on their significance in the econometric regressions, they are determined outside the model (Wooldridge, 2003):

$$TI = b0 + b1\ FE + b2\ TRAIN\_PROG + b3\ EXP + SECTOR \qquad (III)$$

$$EXP = b0 + b1 \ln SIZE + b3\ EDU + b4\ TI \qquad (IV)$$

The variables are:

TI: the Technology Index and reflects the level of TCs in enterprises.

FE: the share of foreign equity, calculated as the percentage owned by private foreign individuals, companies or organizations.

TRAIN_PROG: is a dummy variable to measure if the firm has internal formal training programmes.

EXP: the export dummy is 0 if the firm does not export or 1 if it directly or indirectly exports.

SECTOR: refers to the screened sector according to the ISIC classification (see note 9).

lnSIZE: is measured by the natural logarithmic number of full-time permanent workers at the end of last fiscal year.

EDU: indicates the level of average education attainment of a typical production worker.

We tested for the influence of these variables on the system of equations: foreign equity, training programmes and export on the first equation of the system, with TI as the dependent variable. As suggested by Geroski (1990), we agree that firms may face different technological opportunities in different industries, hence, we decide to control for sectoral effects by including the sector variable in the first equation. Then, with exports as the dependent variable, we include the size (in natural logarithmic form), education and TI as the explanatory variables and expect a positive relationship, consistent with the literature. Other variables, such as age and skilled trained production workers, were not considered in the system of equations because they lack significance for the whole model.

1.6. Results of the analysis

1.6.1. The Data

The empirical part of this work uses data from the World Bank Investment Climate Survey, with samples of representative enterprises in Argentina (2006), Brazil (2003) and Chile (2006). As Brazil's survey was done before the other surveys, it uses a partly different set of questions. Nevertheless, surveys are highly comparable and the format allows cross-country comparisons. Firms are sampled scientifically in order to ensure the survey's statistical representativeness. The survey questionnaire allows analysis of five key areas: the determinants of firm productivity, firm access to finance, characteristics of the labour market (including investments in training and skill building), business environment and obstacles to increasing exports in the regional and international marketplace. The stratification was made on the basis of the following criteria: sector of activity, firm size and geographical location. Stratification by firm size divides the population of firms into 3 strata: small firms (5-19 employees), medium firms (20-99 employees) and large firms (100 or more employees).

These surveys cover mainly manufacturing[9] and certain services for registered firms. For the purpose of our study, we decided to work with manufacturing enterprises only. The level of sector analysis consists of three digit International Standard Industrial (ISI) codes, based on the 1987 International Standard Industrial Classification of all Economic Activities (ISIC). The samples did not cover the same sectors for the three countries. Both Argentina's and Chile's surveys covered Food Processing, Textiles, Garments, Chemicals, Non Metallic Mineral Products, Machinery and Equipment, Other Manufacturing, but the Electronics sector is only present in Argentina's survey. Brazil's survey considered Auto Parts, Chemical, Food Processing, Electronics, Furniture, Garments, Machinery, Shoe and Leather Products and Textiles. This is the main reason to avoid performing a pooled analysis, studying each country separately before proceeding to compare them. In Appendix A, we can see the sample composition by industry and by country. Even if the considered sectors are different from country to country, we perform our study with all of them. The reason for this is that these sectors have been selected because they are representative of each country's industrial reality and it would be biased to exclude any of them. Although the surveys were not conceived for analysing TCs, we found some useful points for evaluating firms' technical functions.

1.6.2. The Technology Index

As stated before, providing information on the level of complexity of these functions, as in Lall (1992), between basic (simple routine), intermediate (adaptative, duplicative) and complex (innovative, risky or research based) capabilities as well as on the paths of TCs accumulation goes beyond the objectives of this Part. Since our

[9] ISIC is a standard classification of economic activities, correspondences with Central Product Classification (CPC) and Standard International Trade Classification Revision 3 (SITC). The categories of ISIC, at the most detailed level (classes), are delineated according to what is, in most countries, the customary combination of activities described in statistical units (activity units). The groups and divisions, and the successively broader levels of classification, combine the statistical units according to the character, technology, organization and financing of production. The population of industries of this survey includes the following list (according to ISIC, revision 3.1): manufacturing sectors (group D), construction (group F), services (groups G and H), transport, storage, and communications (group I), and subsector 72 (from Group K). To limit the surveys to the formal economy, the sample frame for each country should only include establishments with five (5) or more employees. Fully government owned firms are excluded (www.web.worldbank.org)

analysis is based on firms surveys and not on case studies it may be difficult to judge a priori whether a particular function is simple or complex for a firm within a specific sector: more information is dramatically required on their learning stages or their modification or creation phases (Teitel, 1984). Then, based on Wignaraja's TI, we compute a TI for each firm evaluated with reference to qualitative information from firm-level interviews and focus on production and linkage capabilities (Lall, 1987, 1992). Information on investment capabilities was not available.

For functions related to production, Wignaraja (2002) focused on ten technical activities, such as internal reject rates, maintenance awareness, calibration of equipment that regards process engineering, copying, that is considered a product engineering capability and productivity improvement that is seen as industrial engineering. These groups of technical functions can be comparable when the studied firms belong to the same homogeneous sector, This type of analysis is then feasible. However, we argue that it is not viable when considering different sectors that also imply different processes, products and industrial engineering. On the basis of the information available, we choose to work on the following production and linkage functions, similar to the ones selected by Wignaraja but also, in our view, adequate for cross section analysis (see Table 1 and 2). Consequently technical functions such as[10] ISO 9000 status, buying new equipment, improving or introducing products or processes (Wignaraja, 2002) are more interesting for our comparative analysis. These can obviously have different weights depending on the firm and the sector, but are becoming fairly simple technological requirements. They allow us to create a picture which is as comprehensive as possible of TCs in our sample firms (Lall and Latsch, 1999).

For functions related to linkages, Wignaraja (2002) considers two types of relationships: subcontractors linkages and systematic receipt of technology. With regard to our study, information on the relationship with providers (key channel to

[10] Other three relevant production capabilities - for all manufacturing sectors - following Wignaraja and Ikiara (1999) should be energy, water, and recycling programs that are related to process engineering. These optimization activities may be considered part of processes engeneering improvements, within the production capabilities. Unfortunately this information was not provided in the Brazilian Survey and will not be included in our TI since it will avoid making a comparative measure.

acquire TCs), subcontractors[11] and clients would have been extremely useful. Unfortunately, we lack this information and hence, we are limited to using available information on functions such as technology licensed from foreign buyers, the investment in inputs supplied by foreign companies and R&D[12] investments to highlight that technology may have to come from outside the firm and in some cases, from outside the country.

Table 1 shows the means and standard deviations of the selected production and linkage functions in the three countries. Quality certification implies accomplishing processes in a certain way with formal systems for quality control based on final inspection. The buy new equipment function is selected to include the incorporation of new technologies embodied in physical equipment. The introduction of improved process or product functions that may range from minor adaptations to new products for the market, highlights the' decisions by firms to strengthen capabilities and measure if the firm was able to introduce product and process in the last year. The technology and inputs from foreign origins represent the use or not of foreign technologies (embodied or unembodied) over the last year. The R&D variable considers the investment that the firm made on R&D over the last year.

[11] Information on subcontractors was available in the Brazilian survey, but not in the Argentinean and Chilean ones. It was therefore not included in TI, according to the criteria in Note 10. See Figueiredo (2001) for the interesting case of USIMINA's response to the trend of deverticalization in the automobile industry in which the technological requirements of car manufacture have been transferred to steel companies. This meant that USIMINA moved into more complex activities with carmakers involving joint application, design and development of car parts.

[12] R&D investments in these countries infrequently pertain to knowledge creation, and are mostly focused on knowledge adaptation.

Table 1. Mean and standard deviation of production and linkage functions by country

PRODUCTION FUNCTIONS	ARGENTINA 2006	BRAZIL 2003	CHILE 2006
Quality[13]	0.269 (0.444)	0.182 (0.386)	0.241 (0.428)
New equipment	0.008 (0.054)	0.003 (0.036)	0.002 (0.041)
New process	0.583 (0.493)	0.678 (0.467)	0.605 (0.489)
New product	0.657 (0.475)	0.675 (0.468)	0.638 (0.481)
LINKAGES FUNCTIONS	ARGENTINA 2006	BRAZIL 2003	CHILE 2006
Technology from foreign buyers	0.134 (0.341)	0.073 (0.261)	0.138 (0.345)
Inputs supplied by foreign companies	0.717 (0.827)	0.240 (0.570)	0.940 (0.877)
R&D investments	0.005 (0.048)	0.007 (0.046)	0.002 (0.039)

Note: Standard Deviation in parentheses.

In Table 1 the three countries reflect low means in investments in new equipment and R&D. The highest means in new process and new products' variables are shown for Brazilian firms. Argentinian firms are more prone to certify quality and buy new equipment whereas Brazilian firms are the leaders in investing in R&D. Chilean ones receive, on average, more technology and inputs from foreign companies.

To calculate the Capability Score or TI, each firm is evaluated over these two groups of functions as shown in Table 2. Each of the technical activities is graded in two different ways according to which is more accurate. The first way is to give the variable two (0,1) levels and the second case is to give it three alternatives (0, 1 and 2) to represent different levels of competence or investment.

[13] The variables quality, new process, new products, technology from foreign buyers and inputs from foreign companies are dummy variables. The results in Table 2 are therefore the means of the percentages of firms that undertake these technical functions in each country. The new equipment and R&D variables reflect firms' investments in both activities compared to the highest investor in each country and Table 2 shows their means.

Table 2. Production and linkage functions to measure capabilities

FUNCTIONS RELATED TO PRODUCTION	
PROCESS FUNCTIONS	
ISO 9000/QS 9000/ISO TS 16949 STATUS	
No certification	0
Certification	1
Annual expenditure on purchases of equipment[14]	
Low expenditure	0
Medium expenditure	1
High expenditure	2
Introduced new or improved production processes	
No	0
Yes	1
PRODUCT FUNCTION	
Introduced new or improving existing products	
No	0
Yes	1
FUNCTIONS RELATED TO LINKAGES	
OTHER FUNCTIONS	
Technology licensed from foreign buyers	
No	0
Yes	1
Percentage of Inputs supplied by foreign companies	
0 to 20%,low	0
20% to 60, medium	1
60% or more, high	2
Investment in R&D contracting a third party[15]	
Low investment	0
Medium investment	1
High investment	2

The enterprise with the highest grades would have a maximum of 10 points, obtained as the sum of the maximum grade in each function. For better comparison between enterprises, the original grading is divided by the maximum grade (10), thereby

[14] For the three countries, the levels of investment in new equipment and R&D in local currency are the following: level (0) less than 100,000, level (1) between 100,000 and 1,000,000, and level (2) invested more than 1,000,000.

[15] For the three countries, the levels of investment in R&D in local currency were: level 0: less than 100,000, level 1: invested between 100,000 and 1,000,000 and level 2: invested more than 1,000,000

assigning the same relative importance to each of the seven functions.[16] This new value, ranging between 0 and 1, is then a summary score of TCs for each firm in the Argentina, Brazil and Chile samples.[17] The results are presented in Table 3.

Table 3. Average and maximum TI values for Argentina, Brazil and Chile

TECHNOLOGY INDEX (simple average)	ARGENTINA	BRAZIL	CHILE
All firms	0.25	0.18	0.26
	(0.13)	(0.11)	(0.15)
Small firms (5-19 employees)	0.23	0.15	0.21
	(0.12)	(0.10)	(0.14)
Medium firms (20-99 employees)	0.26	0.18	0.26
	(0.14)	(0.10)	(0.14)
Large firms (> 99 employees)	0.30	0.22	0.33
	(0.12)	(0.12)	(0.13)
Maximum Value	0.70	0.60	0,70

Note: Standard Deviation in parentheses

Unexpectedly, Brazil's average TI is the lowest among the three countries. On the one hand, fewer firms in Brazil obtain QC and on the other, technology from foreign buyers and inputs supplied from foreign companies suggest that Brazil is less dependent on foreign technology. This finding is extremely important for characterizing Brazil's industrial system: this country has been constructing a solid technology support system for its industries over several years. Our TI should then take into account some specific assumptions: a higher index notably reflects the capabilities but also the need to assimilate and efficiently operate foreign technology. However, it underplays the fact that within developing countries, important national

[16] As stated by Westphal et al. (1990 pp.87), "the Capability Scores are biased estimates with respect to the measurement of capabilities cum capacities per se. The degree of bias depends on the respective weights placed on capability and sophistication in the researchers' scoring. Unfortunately, these weights cannot be stated…" The overall capability score is often designated as the Technology Index or TI (Wignaraja, 2008).

[17] This is also in line with Wignaraja's (2002, pp.91) procedure for the Mauritius case study: "all the activities are given equal weights by averaging, based on the assumption that they are of similar importance for the capability building process. While this may clearly be mistaken in particular instances, it is difficult to think of a defensible way of assigning different weights across all firms". Nevertheless, to check our statements, in Appendix B we compare two alternative procedures of calculating the TI: one, as suggested by Wignaraja, the other, by weighting the technical functions according to their degree of complexity in basic, intermediate, and advanced (Lall, 1992). Since we are comparing different industrial sectors in three different countries, we prefer the first procedure to avoid weighting mistakes. Nevertheless, the regression results in the two methodologies are quite similar.

technology systems sometimes exist, and this allows national firms to rely on national technology[18]. It does not intend to underestimate the importance of establishing linkages with foreign firms or partners, but only to underline different Brazilian behaviour. Consequently, although we expect TI to give information on overall capabilities of the firms, important insights can be obtained by studying TI building blocks in depth, i.e. production and linkage functions. And most importantly, we consider that this way of calculating TI is useful for reflecting important differences between the three countries studied and their underlying National Systems of Innovation (Lundvall, 1988).

There are notable outliers in the dataset. In Argentina, the maximum TI value is achieved by a large national Food Processing firm that also has the highest investment in R&D in the country. In Chile, the maximum TI value is achieved by a medium-sized, completely foreign-owned, Chemical firm that, as in Argentina's observed firm, undertakes every selected TI's function and sources 70% of its inputs from abroad. The same for Brazil: the highest TI is reached by a large, completely foreign-owned, auto parts firm that undertakes every TI's selected function and sources 80% of its inputs from abroad.

1.6.3. The Technology Index and Export's correlations

Following Equation III, a set of correlations between our TI and some specific firm patterns is given in Table 4.

[18] This is, for instance, the case of China and Sri Lanka clothing firms. In a recent study Wignaraja (2008c) computes the TI considering these firms' competences: search for technology, quality certification, process adaptation, minor adaptation of products and introduction of new products. This is a different analysis from his 2002 study, performed for the Mauritius garment sector when he evaluates, among others, technical activities involving technological interactions with subcontractors and overseas buyers of output. This fact demonstrates that when the specific sectoral systems of innovation are already mature and developed, other technological functions should become more relevant to compute TI.

Table 4. Spearman's Rank Correlations coefficients between TI and other variables

TECHNOLOGY INDEX	ARGENTINA	BRAZIL	CHILE
Size	0.374***	0.320***	0.363***
Foreign Ownership	0.258***	0.284***	0.139***
Age	0.098*	0.139***	0.139***
Education	0.117***	0.281***	0.083
Skilled Trained Workers	0.120***	0.302***	0.076
Export	-0.017***	0.294***	0.334***
Managers' Experience	-0.003	-0.041	-0.069

*Note: * significant at 10%, ** significant at 5%, *** significant at 1%*

TI is positively related to firm size, foreign ownership and age in the three countries. This can reflect the fact that large, experienced foreign-owned firms are the most prone to undertake technical functions for building TCs. The education variable has positive and significant correlation coefficients with TI in Argentina and Brazil which means that technical human skills are crucial in industrial firms in these countries for building TCs. If we consider skilled production workers that received formal training programmes, they are also positively and significantly correlated with TI in both countries. In this case, it implies one step on from just recruiting skilled workers: firms do not only work with production workers that have previous skills or education, but they also keep on improving employees' skills by providing them with training. With regard to the export variable, it is significant in the three countries but only positive in Brazil and Chile, meaning that foreign markets exert an important stimulus for increasing TCs in these countries. Unexpectedly, the results seem to indicate that exports are not positively related to TC building in Argentina. Deeper analysis is needed, sector by sector, to understand the reasons, but one speculation may be that Argentinian firms build TCs but are not always able to reach foreign markets. Finally, the managers' experience variable is not correlated with TI in the three countries. This could suggest that firms do not necessarily rely on their managers' leadership and experience for building TCs or that specialization in new technological activities does not require substantial managers' experience.

In Table 5 we test the correlations and the importance of a group of variables with the export variable calculating Spearman's coefficients. Following equation (IV), the purpose is to test the influence of some firms' characteristics on exports.

Table 5. Spearman’s Rank Correlations coefficients between Export and other variables

EXPORT	ARGENTINA	BRAZIL	CHILE
Size	-0.246***	0.468***	0.403***
Quality Certification	-0.244***	0.314***	0.236***
Foreign Ownership	-0.200***	0.213***	0.158***
Age	-0.142*	0.241***	0.105**
Education	0.055	0.072*	0.012
Skilled Trained Workers	0.015	0.033***	0.149***
Technology from foreign buyers	-0.168***	0.153***	0.170***
Inputs from foreign companies	0.033	0.049	0.155***
R&D	-0.027	0.273***	0.066

*Note: * significant at 10%, ** significant at 5%, *** significant at 1%*

As suggested by Bernard and Jensen (1999), we confirm the hypothesis that size matters for exports in Brazil and Chile. With regard to Argentina, this firm pattern does not exert the same positive effect on exports and is significantly negatively related to them. As stated when considering the influence of firms’ patterns on TCs, deeper analysis is required to understand these results in Argentina, in particular with regard to sectors. In this case, the speculation may be that Argentinian firms’ access to external markets is mostly not due to TC development. It is not only size that matters for firms entering foreign markets. For instance, large firms may move into modern quality management systems by adopting ISO 9000 standards, especially relevant for exports. We argue that quality certification reflects firms’ TCs and, as a single variable, is also expected to be significantly and positively related to the exports. This hypothesis is empirically checked for Brazil and Chile which have positive and significant coefficients. In our case, we verify that the export variable is positively and significantly related to the foreign ownership variable for Brazilian and Chilean firms. This statement cannot be confirmed for Argentina. There are other firm characteristics that are usually related to export performance such as age. Again in this case, Brazilian and Chilean firms show positive and significant relationship with age suggesting that experience seems to be relevant to the exports. Concerning the role of the education level of workers, we expect it to be positively related to exports. We only check this hypothesis for Brazil and for both Brazil and Chile, concerning skilled trained workers. Regarding technology from foreign buyers and inputs from foreign companies, the first variable is positive and significantly related to exports in

Brazil and Chile whereas the second one is only significant for Chile. Equipment and technical assistance are frequently provided by foreign buyers to improve firms' TCs (Wignaraja, 2008) but again we confirm that Brazilian firms are not dependent on foreign inputs for exporting, but they also rely on the domestic market. If we consider R&D investments, this variable is only positive and significantly related to exports in Brazil, confirming the importance given by Brazilian firms to this issue.

1.6.4. The estimation issues and results

As TCs are intrinsically related to exports, we expect the variables TI and EXP in Equations (III) and (IV) to simultaneously determine each other. Indeed, they are analysed under a simultaneous equation model that takes the following form:

$$Y_1 = \gamma_1 Y_2 + \beta_1 X_1 + \varepsilon_1 \qquad \text{(V)}$$

$$Y_2 = \gamma_2 Y_1 + \beta_2 X_2 + \varepsilon_2 \qquad \text{(VI)}$$

where Y_1 and Y_2 correspond reciprocally to TI and EXP, are endogenous variables and are correlated with the error term; γ_1 and γ_2 are the parameters of the endogenous variables; X_1 and X_2 is the set of all exogenous variables (uncorrelated with the error term), and β_1 and β_2 are vectors of parameters for the exogenous variables; and ε_1 and ε_2 are respectively the error term for (V) and (VI). When analysing simultaneous equation models, standard estimations methods are not advisable since they can generate biased and inconsistent results (Keshk, 2003). Besides, the dependent variable Y_2 (EXP) is dichotomous and represents that fact that a firm exports (1) or not (0). We denote the variances and covariance of (ε_1, ε_2) by σ^2_1, σ^2_2 and σ_{12} respectively and we assume, in addition to the usual identifiable condition, a normalization σ^2_2, =1. This condition is required since Y_2 is only dichotomously observed: one could identify Π_2 and hence some of the structural parameters only up to a scalar multiple without this normalization (Amemiya, 1978). Our empirical analysis has the following form:

$Y_1 = Y^*_1$

$Y_2 = 1$ if $Y^*_2 > 0$

$Y_2 = 0$ otherwise

The application of OLS or Probit models to Equations (III) and (IV), without correcting for endogeneity, will most likely result in biased coefficients and incorrect inferences. The most important problem is consistency. Estimations can take different alternative directions and we choose to create a variable called "instrument" that is highly correlated with the endogenous variable and uncorrelated with the disturbance term. We create[19] this variable following a Two Stage procedure model with mixed dependent variables, one continuous and one dichotomous, and separate the endogenous variable into two parts, one correlated with the disturbance term and the other uncorrelated with the disturbance term (Keshk, 2003). We work, for the first stage, with the reduced forms for Y_1 and Y^*_2 (Maddala, 1983, p.244):

$$Y_1 = \Pi_1 X + \upsilon_1 \quad \text{(VII)}$$

$$Y^*_2 = \Pi_2 X + \upsilon_2 \quad \text{(VIII)}$$

and we estimate the reduced form for Y_1 by OLS and the reduced form for Y^*_2 by the Probit method, obtaining the predicted values (Maddala, 1983).

In the second stage (IX) and (X), the original endogenous variables are replaced by their fitted values in (VII) and (VIII) and the OLS and Probit are again respectively used.

$$Y^*_1 = \gamma_1 \hat{Y}^*_2 + \beta_1' X_1 + \varepsilon_1 \quad \text{(IX)}$$

$$Y^*_2 = \gamma_2 \hat{Y}^*_1 + \beta_2' X_2 + \varepsilon_2 \quad \text{(X)}$$

Finally, the standard errors are corrected since they are based on the predicted Y_1 and Y^*_2- (Keshk, 2003) obtaining the results showed in Table 6. We perform the Wald test for all the variables of both equations in pairs. The obtained p-values allow us to reject the null hypothesis, indicating that including these variables create a statistically significant improvement in the fit of the model.

To our knowledge there are no heteroschedasticity tests on finite samples for our two stage Probit. Borjas and Sueyoshi (1994) perform the heteroskedasticity correction to account for the variability of the first stage estimates of what they define as the "group effect dummy", but using the asymptotic standard errors for the first-stage fixed effects estimator and the estimator for the variance of the σ^2. This problem could therefore only be effectively resolved according to the primary assumption that individuals per group approach infinity.

[19] Keshk (2003) suggests that instruments can be found or created. With regard to the former, this is usually very difficult and when one of them is found, its suitability is questioned. The most common avenue taken by researchers is therefore to create an instrument, using the method of two-stage least squares (2SLS).

Table 6. Two Stage Probit Model – Argentina, Brazil and Chile

First Stage Regressions	Argentina	Brazil	Chile
Technology Index	Coef.	Coef.	Coef.
Train	0.082***	0.033***	0.076***
Fe	0.001**	0.002***	0.000**
Sector	0.010***	-0.009***	0.012***
Edu	0.150***	-0.0218***	0.240***
Ln Size	0.026***	0.020***	0.039***
R-squared	0.218	0.197	0.244
Prob>F	0.000	0.000	0.000
Export	Coef.	Coef.	Coef.
Train	-0.239*	0.213***	0.546***
Fe	-0.005**	0.008***	0.003
Sector	-0.031	-0.017	2.21E-05
Edu	0.731	0.572***	0.434***
Ln Size	-0.247***	-0.065	0.17
Log Likelihood	-259.792	-776.543	-299.931
Pseudo R2	0.115	0.112	0.203

Second Stage Regressions with instruments	Argentina	Brazil	Chile
TI	Coef.	Coef.	Coef.
Instrumented Export	-0.079***	0.038***	0.092***
Train	0.073***	0.030***	0.029
Fe	0.001*	0.001***	0.000
Sector	0.008**	-0.008***	0.012***
R-squared	0.192	0.187	0.232
Prob>F	0.000	0.000	0.000
Export	Coef.	Coef.	Coef.
Instrumented TI	-3.805***	-3.80***	3.683***
Edu	1.295**	1.295	0.339***
Ln Size	-0.159***	-0.160***	-0.689
Log Likelihood	-260.668	-776.543	-303.919
Pseudo R2	0.112	0.214	0.192

Second Stage Regressions corrected standard errors	Argentina	Brazil	Chile
TI	Coef.	Coef.	Coef.
Instrumented Export	-0.079***	0.038***	0.092***
Train	0.073***	0.030***	0.029
Fe	0.001	0.001***	0.000
Sector	0.007**	-0.008***	0.012***
Export	Coef.	Coef.	Coef.
Instrumented_TI	-3.805***	4.368***	3.683**
Edu	1.2952**	0.492	-0.689
Ln Size	-0.159**	0.026***	0.338***

Source: World Bank Business Climate Survey. Argentina and Chile 2006; Brazil, 2003

*Note: * significant at 10%, ** significant at 5%, *** significant at 1%*

Table 6 illustrates the results from the Probit Two Stage regressions for the three countries' databases. Brazil and Chile confirm our original hypothesis of the positive and significant influence of TI on exports. This is also true in the opposite sense: in both countries, exports also exert positive and significant coefficients with TI. As previously verified in Tables 5 and 6, both relationships are significant and negative, regarding Argentina, probably suggesting low levels of TCs in exports.

In Argentina, education contributes significantly to building TCs. Despite the results obtained while considering the Spearman's correlation coefficients for exports, one interesting finding when studying TCs and exports under a simultaneous equation approach is that the variable is now positive and significantly related to both of them. This fact may confirm our hypothesis of the existence of a reciprocal relationship between TCs and exports: once taken into consideration, new, different results may emerge. The training programme variable is also positive and significantly related to both dependent variables of the system, as expected. The foreign ownership variable exerts a positive significant sign only when analysed over TCs. Again, Argentinian firms seem to have difficulty in exporting TCs embodied products even if they belong to foreign companies. The variable sector has also a positive and significant coefficient in the TI-Exp equation systems. It gives the idea that there are shared realities within specific sectors, characterizing them in both senses: in their TC approach and also in their access to foreign markets. Size, in this case, does not contribute to gaining TCs or to exporting.

Almost all the selected firms' patterns, except education, have significant, positive impacts on the TI-Exp equations system in Brazil. This means that these parameters allow firms to create skills, induce in-house efforts for building TCs and eventually use them for export. With regard to the negative coefficient of the sector variable in both equations, this may suggest that there are no shared characteristics within them and may be related to the different regional realities of this huge country.

Chile shares the positive and significant impact of the sector variable in the system with Argentina, probably due to the same reasons. The difference is that size matters in Chile: large firms are able to build TCs and export probably allowing them to lower production costs, improve business productivity and take advantage of international market opportunities (Goldberg and Palladini, 2008). Education, training and foreign ownership are not significant in this TI-Exp system.

The overview of Latin American industrial development that we present in the present study includes almost half a century in which there have been alternating periods of varying emphasis on learning and investing in technology. Our empirical evidence confirms that nevertheless, the three countries have undergone similar historical paths, from the ISI period to trade liberalization, their technological development has been evolving in a different way and firms within these countries are facing different realities regarding TCs and exports (see Table 6). Among the endogenous factors, the focus on developing strong indigenous human capital, skills and training has been central issues for unevenly creating and accumulating TCs. Among the exogenous ones, strategic industrial national policies that accompany firms' technological efforts have also been contributing to this divergent behaviour.

Thus, the results may be interpreted as follows: TCs, firms' size, foreign ownership and human capital are important determinants of export advantage and, in turn, exporting firms build TCs by continuously improving and exporting. The accumulation of TCs is a critical task for companies to overcome technological barriers (Figueiredo, 2001), catch up with technological change and eventually export. With all its limits, the importance of these results rests on the fact that they come from an inter-firm and inter-country and that they provide the basis for comparative analysis of TCs within industrial sectors in different countries.

1.7. Concluding remarks

This first Part analyses the Latin American industrial evolution, from the ISI period through to trade liberalization, with special interest on its impact on the patterns of technological behaviour and firms' learning processes by measuring TCs at the firm level and exploring their determinants.

Different strands of literature have explored the process of knowledge conversion ranging from the Absorptive Capacity approach, the Resource Based View and the Dynamic Capabilities and finally the Knowledge-based View and Technological Capabilities. We focus on the latter approach, analysing it within two basic theoretical frameworks: the Technological Frontier Companies Literature and the Latecomer Companies Literature. Even if both views have strengths and weaknesses, they provide us with interesting theoretical and empirical insights into firms' technological capabilities and their determinants.

The nature and determinants of firms' TCs remain at the core of our analysis. In particular, we concentrate on the reciprocal influence between them and exports. Alternative ways of measurement are studied suggesting that a deep understanding of firms' learning processes and capabilities accumulation is obtained from case studies, with the shortcoming of losing comparative power. The conversion of individual into organizational learning frequently remains a still unexplored issue. Interesting findings are obtained when examining inter-firm differences regarding these aspects and quantitative analysis fill part of this gap.

Our model proposes an overall capability score as a qualitative-quantitative measure of TCs. After considering some of its weaknesses, it remains our best option for constructing a comparable proxy of TCs for the industrial sector in the three countries. Indeed, this measure also allows us to study the importance of some firms' patterns as drivers of TCs and exports. Finally, the reciprocal relationship between exports and TCs is also considered.

For empirical analysis, we use the most recent World Bank Investment Climate Surveys. Our empirical econometric model consists of two equations, one related to TCs and the other related to exports- and we study them under a Two Stage Probit model. The results of the estimates are sufficiently robust to provide original insights. We will briefly summarize them.

First of all, our measures suggest that the three countries' manufacturing enterprises have different levels of TCs. However, we cannot make generalizations about these levels since there are remarkable outliers such as specific firms within specific sectors that have high levels of TI as a result of different levels of accumulation of TCs.

Secondly, firm size is relevant to building capabilities. In Argentina, Brazil and Chile, larger firms have higher TIs than medium and small ones. Nevertheless, when the size variable is analysed within the TCs-exports system, size remains an important factor for both building capabilities and exporting only for Brazil and Chile. Moreover, we observe positive and significant correlations with TI for the other variables such as age, education, skilled trained production workers, foreign ownership and exports. As far as exports are concerned, relevant firm-level characteristics include quality certification, technology received from foreign buyers, foreign inputs and R&D. Our results support the view that the process of building TCs requires firms' continuous efforts and adequate linkages to absorb external knowledge.

The evidence supports the hypothesis that TI and exports mutually influence each other in Brazil and Chile. Within this context, variables such as education and training matter for Argentina, whereas education is not relevant for Brazil and training and foreign ownership are not relevant for Chile. We do not intend to neglect the importance of organizational and managerial aspects: we only expect to highlight some aspects that are at the basis of TCs. Since we are not working with case studies, we are not able to draw conclusions about the complexity and cumulativeness of TCs within firms but we expect to provide a starting point for future refined analysis on key aspects that influence TCs building. We argue that TCs are extremely important for catching up with the technological frontier and for exporting. Firms' continuous and deliberate efforts are needed in a context of accelerated technological change.

However, these results have to be interpreted with caution. The present TI embeds an important component of foreign technology dependence. This is the reason why, unexpectedly, Brazil had the lowest TI, in spite of having the most advanced national technology system whereas TI works, as expected, in the other two countries. This finding does not intend to underestimate the importance of foreign linkages, but is extremely useful in confirming our assumption that the three countries studied have different levels of foreign technology dependence.

Finally, we intend to highlight that the discontinuity in building TCs has generated many years of delay in the processes of learning and accumulating technological knowledge and consequently more predictable scenarios would help to accelerate the rate of technological improvements.

Additional limitations to Part I, that will be addressed in Part III, refer to the static nature of the analysis. We could not capture changes in TCs as data for only one year were available. Moreover, inter-industry differences exist and are being properly addressed in Part II.

APPENDIX A: *Sample Composition by industry and by country*

INDUSTRIES	ARGENTINA 2006		BRAZIL 2003		CHILE 2006	
	Number of firms	Percent	Number of firms	Percent	Number of firms	Percent
Autoparts	0	0.00	131	7.98	0	0.00
Chemicals	67	8.98	84	5.12	74	10.62
Electronics	1	0.13	78	4.75	0	0.00
Food processing	167	22.39	129	7.86	160	22.96
Furniture	0	0.00	317	19.31	0	0.00
Garments	119	15.95	441	26.86	72	10.33
Machinery and equipment	127	17.02	184	11.21	33	4.73
No metallic products	3	0.40	0	0.00	4	0.57
Other manufactures	145	19.44	0	0.00	305	43.76
Shoe and leather products	0	0.00	174	10.60	0	0.00
Textiles	117	15.68	104	6.33	49	7.03
TOTAL	746	100	1642	100	697	100

APPENDIX B: *Different ways of calculating TI*

Methodology I: All the activities are given equal weights

Methodology II: The production and linkages functions are classified and weighted in this way:

- Basic functions: purchase new equipment, received technology from foreign owned company (multiplied by 1)
- Intermediate functions: certifying quality and investing in R&D (multiplied by 2)
- Advanced functions: introduce new process and new products (multiplied by 3)

Mean and maximum TI values for Argentina, Brazil and Chile – With weighted and unweighted TI

	ARG 2006			BRA 2003			CHIL 2006		
Simple Average:	**I**	**II**	Change	**I**	**II**	Change	**I**	**II**	Change
All firms	0.25 (0.13)	0.59 (0.30)	57.63%	0.18 (0.11)	0.52 (0.3)	65.38%	0.26 (0.15)	0.69 (0.38)	62.32%
Small Firms (5-19 employees)	0.23 (0.12)	0.54 (0.30)	57.41%	0.15 (0.1)	0.4 (0.24)	62.50%	0.21 (0.14)	0.54 (0.35)	61.11%
Medium Firms (20-99 employees)	0.26 (0.14)	0.61 (0.30)	57.38%	0.18 (0.1)	0.49 (0.27)	63.27%	0.26 (0.14)	0.72 (0.36)	63.89%
Large firms (> 99 employees)	0.34 (0.15)	0.83 (0.40)	59.04%	0.22 (0.12)	0.68 (0.34)	67.65%	0.33 (0.13)	0.86 (0.35)	61.63%
Maximum Value	0.7	1.7	58.82%	0.6	1.6	62.50%	0.7	1.7	58.82%

Note: Standard Deviation in parentheses

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PART II: INNOVATION IN LATIN AMERICA: A SECTORAL SYSTEM ANALYSIS OF THE FOOD PROCESSING SECTOR IN ARGENTINA, BRAZIL AND CHILE

2.1. Introduction

As suggested in the Introductory Part and Part I, one effect of external liberalization in Latin America has been the increase opportunity to access knowledge and technology. This has impacted this sector in at least two senses: on the one hand, the fall of tariff and non-tariff barriers has promoted the importation of technology (Katz, 2001), thus avoiding or hampering the local development of some industrial sectors (Farina, 2001). On the other hand, the access to foreign knowledge has allowed firms to incorporate many technological advances (biotechnology, packaging, transport techniques, etc.) (Marsden and Arce, 1995; Bisang and Gutman, 2005).

We selected this sector in these three Latin American[20] countries as it represents between 40-50 per cent of exports, 10-15 per cent of GDP, and 15-30 of employment. The sector's importance increased between 1970 and 2003, and the exports of processed goods have followed in the same fashion in the last decade. Different levels of processing have implied different export destinations - with the increasing importance of Asian countries as a main destination (ECLAC, 2007).

Another reason of interest is that the Food Processing Sector appears to offer a fruitful arena in which to examine the heterogeneity of modern production systems (Murdoch *et al.*, 2000). Idiosyncratic production systems, with specific productive and organizational skills and specific features of domestic demand, coexist with others that are more standardized and global.

It is also known that the Food Sector is tending strongly towards greater technological sophistication and innovation, as a result of product differentiation and key consumer issues, such as food origin and safety, as well as the indispensable incorporation of services for marketing (logistics, packaging, transport, and distribution in general, including the improvement of customs offices and port logistics for exports) (ECLAC 2008, Wilkinson, 2003).

[20] "The agrifood complex is crucial in Latin America and the Caribbean, for a number of reasons: it makes a valuable contribution to the food supply and to food safety, generates demand for labor (18% of employment in 2005), occupies national territory (at least 50% of surface area is devoted to crop and livestock farming and the first stages of related industry), creates linkages with other sectors and activities, contributes to exports (16% of the region's total in 2005 and more than 50% in many countries) and, lastly, represents a strategic alternative energy source" (ECLAC, 2008).

While we could focus at different levels of the economy to study innovation, for the purpose of this work we selected to focus on the Sectoral System of Innovation (SSI) approach. It is defined as "the set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products" (Malerba, 2002, pp. 248). This vision is particularly useful within the Food Processing Sector, considering the strong and systemic relationships between agents, linkages, and institutions.

Most of the sector case studies focus on a single dimension (such as innovation, firms' competencies, structure of production, etc.), and have a different level of aggregation in terms of units of analysis. As a consequence, the possibility of having an integrated and consistent analyses of sectors, understanding fully their workings and comparing different sectors with respect to several dimensions (such as the type and role of agents, the structure and dynamics of production, the rate and direction of innovation and the effects of these variables on the performance of firms and countries) is still very limited (Malerba, 2002). This study expects to contribute to filling this gap, but requires one important caveat: this sector includes many different and heterogeneous activities that must be properly and individually analyzed. However, our aim is to give a glance to the "whole", leaving for future research the analysis of the "parts". This strategy allows us to compare the same sector among three countries and can also be a starting point for future comparison with other sectors.

As the innovation process is an intricate interplay between micro and macro phenomena, (where macro-structures condition micro-dynamics and, vice versa, new macro-structures are shaped by micro-processes) (Lundvall, 2007), the frequent use of R&D statistics and patents as proxies for measuring innovation is acknowledged to be unsatisfactory (Winter, 1987; and Bell, 1984; Freeman, 1994). Especially for developing countries, other factors matter for innovation. R&D is only complementary to "efforts" embodied in people and firms, which are obviously more difficult to trace (Dosi, 1988). For all of these reasons, we expect to approach the innovation process through a systemic view.

We theoretically evaluate the Food Processing Sector's main building blocks. Under an integrated and systemic view, agents, linkages, and institutions, influence firms' probability to introduce new products and new processes. On the one hand, firms require indigenous capabilities to search for and create new knowledge, partly by formal R&D and partly by less formal types of technological effort. On the other hand, university research, vertical and horizontal links among local firms, user-producer interactions, and the level of firms' innovative efforts (Nelson, 1991) are extremely important and generate opportunities or constraints for firms.

Based on the General System theory, we empirically focus on firms. As main actors of this system that undertake innovations (and they themselves are systems of a next lower order that share the same characteristics with original systems) (Von Bertalanffy, 1950). Based on a descriptive analysis of the Food Processing SSI components, our research question looks for recognizing the factors affecting innovation within this SSI and the interaction between firms' knowledge base and other stimuli, generated by the supply of the appropriate level of education, skills, as well as the supply of training, and investments in R&D and new equipment (first SSI building block), their linkages and networks (second SSI building block), and the shaping institutions (third SSI building block) that eventually result in the introduction of new products and new processes.

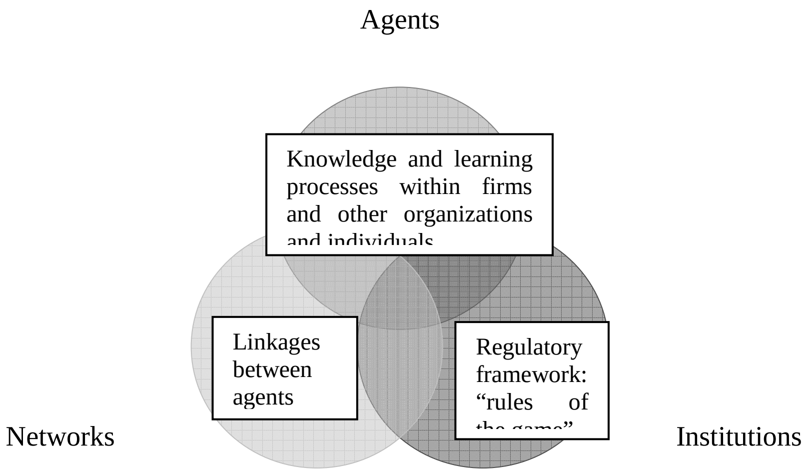
The SSI approach has been widely used for studying different manufacturing sectors (Malerba, 2004; Malerba and Montobbio, 2004) and it also seems particularly appropriate for analyzing the Food Processing Sector. Indeed it contributes to explain its complex knowledge base and its qualitative shift (Murdoch *et. al*, 2000), the crucial importance of networks, as well as how capability and institutions have been coping with the changes of the sector in knowledge and technological base (Gu *et al*., 2009).

2.2. The Sectoral System approach in the Food Processing Sector

Combining the Sectoral System and Innovation[21] concepts, Malerba (2002) suggests an integrated and dynamic view of sectors –the Sectoral Systems of Innovation[22]

(SSI), which includes microeconomic, technological, and institutional factors as sources of differential innovativeness across sectors. This notion provides a set of variables and concepts that can be identified in *three building blocks*: *a) knowledge and learning processes, b) actors and networks, and c) institutions* (Malerba, 2005). These blocks have many overlaps, as is natural under a systemic conception (see Graph.1). We consider that *knowledge and learning* are crucially built by *agents*. Thus, for the purpose of this study, we name the first building block *"agents"*.

Graph 1. The SSI's building blocks



The three building blocks should not be seen as just a static structure. Change is a distinctive feature of Sectoral Systems, which means transformation and evolution (Malerba, 2002), as well as the need for continuous innovation. Connecting the second and third building blocks (networks and institutions), network analysis implies

[21] The Innovation System approach (Lundvall, 1993; Carlsson, 1995; Edquist, 1997) considers innovation as a collective and interactive process among a wide variety of actors. Firms interact between them, but also with non-firms organizations putting learning as a key determinant of innovation (Edquist, 1997).

[22] The earliest versions of this concept were coined by Freeman and Lundvall (Lundvall, 1985; Freeman, 1987). Carlsson and others developed the concept ''technological systems'' at the beginning of the 1990s (Carlsson and Stankiewicz, 1991). Meanwhile the literature on ''Regional Systems of Innovation'' has grown rapidly since the middle of the 1990s (Cooke, 1996; Maskell and Malmberg, 1999) while according to Chris Freeman[22], the first person to use the expression "National Systems of Innovation" was Bengt-Åke Lundvall (Freeman, 1995). The concept of ''Sectoral Systems of Innovation'' has been developed by Malerba and others (Breschi and Malerba, 1997; Malerba and Orsenigo, 1997; Malerba, 2002; Malerba, 2005). Some of the crucial ideas inherent in the innovation system concept (on vertical interaction and innovation as an interactive process) appear in Porter's industrial clusters as well as in Etzkowitz and Leydesdorff's Triple Helix concept (Etzkowitz and Leydesdorff, 2000).

that market activities are never purely economic but are embedded in social norms and institutions which mediate their effects (Polanyi, 1957). Moreover, institutions (in one of the most highly regulated sectors in the global economy- matter a lot and political regulation guides agro-food chain governance and shapes meanings and practices across agro-food networks (Ponte 2002a, 2002b; Raynolds, 2004).

Within an interactive innovation model there are a plurality of production systems and innovation processes, where informal practices and institutions frame networks and agents (Storper and Scott, 1995). For example, agents can be fostered or hampered by institutions. More, firms can encounter opportunities related to the availability of an adequately educated labor force but they may find obstacles due to governments' labor regulations. In the same fashion, firms can be encouraged to build their own capabilities -and finally to innovate- through regulations' flexibility[23], knowledge and research availability, and taxes incentives, or may find many obstacles in each of the mentioned issues. Non-firm agents, such as universities, research centers and other sector organizations, may also find the same alternative context of opportunities or obstacles. Thus, within this SSI, there is always a feedback loop due to inherent dynamics and reciprocal influence: the creation, the diffusion and the application of knowledge that takes place through interactions between various actors of the innovation system (Lundvall, 1992; Nelson, 1993; Gu et al., 2009) influenced by surrounding institutions. In the following paragraphs, we will look deeply into each building block for the SSI agro-food.

2.2.1. Agents

SSI are composed of heterogeneous agents that are organizations and individuals. In the first group, there are firms (users and producers) and non-firms (universities, research centers, etc.). In the second group, there are consumers, entrepreneurs, and scientists. Knowledge and technologies are important constraints or strengths of agents, and consequently of sectors.

[23] As an example of the release of regulations in the sector, Bisang and Gutman (2005) report the elimination, in Argentina and other countries, of mechanisms regulating some production activities (in Argentina, the National Grain Board, the National Meat Board, the Dairy Industry Coordination Commission, etc.) and their replacement by the competitive pressure of foreign markets, after the changes in regulatory and institutional context in the 90s.

Focusing on the Food Sector, it is not "immune" to the increase in the importance and the change in the roles of user-producer interaction (Lundvall, 1988; Gertler, 1995). Knowledge does not flow unidirectionally from technology producers to users, as users provide tacit and codifiable[24] knowledge to producers, in order to enable the latter to solve their practical concerns (Asheim and Gertler, 2006). This is made evident in consumers' increasing demand for product quality and safety. Focusing on firms' efforts, they are then directed to quality and safety characteristics. They constitute "credence attributes" and comprise: (1) food safety; (2) healthier and more nutritional foods (low-fat, low-salt, etc.); (3) authenticity; (4) production processes that promote a safe environment and sustainable agriculture; (5) "fair trade" attributes (for instance adequate working conditions).

The specific knowledge base tends to vary across industrial subsectors within the Food Processing SSI, and shapes the innovation process of firms (Pavitt, 1984). This knowledge base can be "analytical" or "synthetic" (Laestadius, 1998), entailing different "mixes" of tacit and codified knowledge, different skills, and realiance on different organizations.

Indeed, the food processing sector embraces many industries. Some of them are dominated by an analytical knowledge base, where knowledge creation is based on codified science (genetics, biotechnology, nanotechnology, etc) (Asheim and Gertler, 2006). Firms typically have their own R&D laboratory, but they also rely on the research undertaken in national research centers and universities for shared scientific principles. Knowledge inputs and outputs in this type of knowledge base are often more codified than in the case of synthetic knowledge (Asheim and Gertler, 2006), but always coexist with tacit knowledge (Johnson *et al.*, 2002). Knowledge application frequently takes the form of radical innovations and results in new firms and spin-off companies (Asheim and Gertler, 2006).

In other industries (production and packaging of chocolates and sweets; processed meat, fish, fruit, vegetables, etc.), a synthetic knowledge base prevails, mainly applying industry-specific technical knowledge (Asheim and Coenen,2005), and innovation takes place through the application or novel combination of existing

[24] Everything that can be articulable is codifiable. The dichotomy between codifiable and non codifiable is highly problematic as, on the one hand, any body of knowledge might be codifiable to a certain extent but on the other hand, it may not be completely codifiable, without losing some of its characteristics (Johnson et al.,2002)

knowledge, and takes the form of applied research involving incremental innovation through the modification of existing products and processes development (Asheim and Gertler, 2006). Thus, constant improvements of pre-existing product standards, packaging, design, and labelling characterize innovation in these industries (Onsager and Aasen, 2003). Additional aspects call for investment in technological assets and knowledge, such as the product differentiation and the specialization strategy geared towards the consumers demand in the international market, and also to the increasingly demanding domestic market (Reardon *et al.*, 2001). Knowledge is created through testing, experimentation and practical work, and consequently tacit knowledge, craft and practical skills, and training, remains more important and are created from experience through learning by doing, using, and interacting. New firms and spin-offs are less frequent than in industries dominated by analytical knowledge (Asheim and Gertler, 2006).

A special mention should be made of public research institutes in the Food Processing Sector. Activities of public science and technology institutions play a crucial role, especially if oriented towards fundamental research. Non-firms agents, like universities, research centers, and other research organizations, at both the national and regional levels need to be "hands-on", which means they should establish systemic relationships with local industries, actively tailored to them (Asheim and Coenen, 2005).

2.2.2. Networks

Networks are important and complex within the Food Processing Sector, and this aspect can differ depending on specific subsectors. Links between research centres and universities with firms can underpin original scientific ideas for food companies (Asheim and Coenen, 2005). Agents interact through processes of communication, exchange, cooperation, competition, and command. "Social capital[25]" (seen for instance as mutual trust), is a prerequisite to promote cooperation within networks, however it is not a guarantee for long-run innovativeness (Asheim, 1999).

[25] Putnam defines "social capital" as the "features of social organization, such as networks, norms, and trust, that facilitate action and cooperation for mutual benefit" (Putnam, 1993, p.1).

Knowledge networks and flows are then, important sources of innovative ideas (Asheim and Gertler, 2006). Networks' perform important missions[26], such as promoting knowledge sharing and competence dissemination among firms, and educational and R&D organisations. Fluency of communications depends on the firms' knowledge base, structure, and internal mechanisms: if well developed, they could simplify the transfer or reception of knowledge. Indeed, firms' background knowledge may contribute, for instance, to facilitate or hinder their relationship with both buyers and suppliers, and also with R&D centers, universities, etc.

Interactions between actors produce, for instance, a shift from "mass markets" (with broad commodities) to markets with differentiated products and niches. The demand side is pushed by mature consumers with sophisticated and varied tastes and the supply side is shifted by production, processing, and distribution technologies that allow product differentiation and market extension and segmentation (more concerned with health and quality considerations) (Murdoch et al., 2000).

2.2.3. Institutions and norms

The third building block includes institutions and norms. Institutions are the "rules of the game" in a society, and affect economic performance by determining the costs of transacting and producing. Efficient rules also provide incentives for the acquisition of knowledge and learning, and also induce innovation (North, 1992).

"Agents' cognition, actions, and interactions[27] are shaped by institutions, which may be formal or informal, including norms, rules, laws, standards, informal constraints, conventions, routines, common habits, and established practices, etc. They may range from ones that bind or impose enforcements on agents, to ones that are created by the interaction among agents (such as contracts)" (Malerba, 2005). Sometimes, they have the goal to prevent "opportunistic behaviors" among competitors (patent protection)

[26] Asheim and Coenen (2005) consider two different situations within regions. One is about Rogaland cluster, where knowledge flow and cooperation are favoured by proximity. In the other case, Scania cluster, firms are involved in collaborative research at all geographical levels.

[27] Productive activities have a form of "collective action" (Callon, 1991; Storper, 1993; Murdoch *et al.* 2000) which relies upon the coordination of various entities within some type of action framework (network, filiere, chain). Indeed, at the heart of any collective action there are "practices, routines, agreements, and their associated informal and institutional forms which bind acts together through mutual expectations" (Salais and Storper 1992, 174).

or to alter the terms of agreements. Other times, they develop problems of bureaucracy that may result in income dissipation and lack of flexibility (North, 1992).

Many institutions are national and shared by all sectors (such as the patent system), while others are specific to the specific sector (sectoral labor markets or sector specific financial institutions) (Malerba, 2005). Considering the Food Sector, some institutions are committed to the communication of quality and safety through grades and standards[28] (G&S) reflected in certification and labels. These mechanisms are needed in order to meet public and private quality and safety requirements and reduce transport and transaction costs (Reardon *et al*., 2001).

Finance support is crucial for this SSI (Intarakumnerd, P., 2011). It can enhance investments in R&D, in machinery and in equipment, as well as expenditures in marketing and processes improvement. The public sector plays a major role in funding R&D activities[29] (Sunding and Zilberman, 2001), and in supporting SMEs (Grunert et al., 1997). In this sense, prizes for discoveries or subsidies for innovations (Sunding and Zilberman, 2001) and exports (Wilkinson, 2003) should not be neglected: they promote specific industries or activities, can help to deal with uncertainties regarding the benefits of innovation, and can spawn social gains (not limited to producers but extendable to consumers) (Sunding and Zilberman, 2001).

Regarding the regulatory framework, tariff and non-tariff barriers also affect this SSI. Besides trade barriers, other policy protective interventions are related to public subsidies and price support measures. If correctly targeted, protection measures can be extremely useful. However, sometimes they stimulate firms' inefficient performance, lack of innovation, or lack of stimulus for exports.

2.3. The SSI Food Processing Sector in the selected countries

The Food Sector, broadly defined for the purpose of this study, is being shaped by a number of processes of changing knowledge and technology in the selected countries.

[28] G&S consist of standards ("rules of measurement established by regulation or authority") and the grades thereof ("a system of classifications based on quantifiable attributes") (Reardon et al. 2001, Jones and Hill, 1994).

[29] As for some agro-food products supply elasticities are relatively low producer surplus is likely to decline with expanded innovation research. Then in certain situations research is not feasible unless producers are compensated. For a broader analysis see Sunding and Zilberman (2001).

Inside this broad vision there are very different activities and realities: from the "big chains" of commodities to the production of wines, from the production of citric juices to the production of sunflower oil. There are extremely different sub-sectors under this classification and consequently it is difficult to make deep characterization of them, even if they share many patterns regarding innovation.

Agents in the sector are very heterogeneous in terms of the scale of activities, age, specialization profiles, and human and economic resources in these countries. There is however, a highly diffused pattern considering in particular firms: they face problems related to the lack of competiveness, and quality, as well as the need of adaptation to the challenges of new markets (Bocchetto, 2001).

Non-firm agents play a fundamental role and can help firms overcome the previously mentioned problems, bringing the necessary means to face technological changes. For instante, PROCISUR *(Programa Cooperativo para el Desarrollo Tecnologico Agroalimentario y Agroindustrial del Cono Sur)* carries on joint research at regional level. It represents the cooperative effort of the different Agricultural National Research Institutes from Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay. Its objectives are to promote the technological integration in the region and to develop regional systems of innovation focused on the generation of the knowledge and the technology needed within the Mercosur (Bocchetto, 2001).

Among non-firm agents there are also national R&D centres, related to industries dominated by analytical knowledge, which coexist with regionalized centres[30], focused on specific agricultural outputs that prevail in the particular area. Outstanding examples of successful cooperation for promoting innovation are the Brazilian “green revolution” fostered by Embrapa in Cerrado; as well as the targeted efforts of firms, universities and research centres, to develop breakthrough innovations in genetic for Eucalyptus. Other positive experiences are related to collaboration in biotechnology, such as the Argentinean alliance between local firms and research centres to develop a new type of bio-milk (Marín et.al, 2009) and the Chilean vaccine for salmon (Maggi, 2007; Marín et.al, 2009). However, public research institutes still have serious budgetary problems (associated in part with the financial crises of the States in question) which have led to budgetary cuts (Beintema *et al.*, 2001; Bisang and

[30] Inta Argentina has 3 regionalized divisions with numerous research centres, Embrapa Brazil works as a network composed of 41 decentralized centres that are distributed among the Brazilian regions, Inia Chile is divided in 10 regional research centers.

Gutman, 2005). At different levels, the three countries' R&D public investments are low and inferior to US or EU expenditures in the Food Processing Sector (Anlló and Suárez, 2008).

Even less frequent is public research involving synthetic knowledge. Research centers need to work in tune with firms, but unfortunately weak links characterize the relationship between different public research institutes and firms within this SSI (Ekboir, 2003): most of the times they deal with partial aspects and have no global strategies. In Argentina, CIDCA is a multidisciplinary center (between University of La Plata and other research centers), focused on food processing and conservation, which undertakes research, and delivers also regulations and quality standards, training, and transfer knowledge to firms. A similar role is played by Intal Brazil and Inta Chile. Albeit one of research centers' goals is the interaction with the private sector, the cooperation among both groups is not very diffused, and not always related to applied research[31]. Also concerning synthetics knowledge, there are successful examples of cooperation, such as the Zero Tillage package in Brazil (Ekboir, 2003) and Argentina (Marín et.al, 2009) where the association between machinery domestic producers and research centers, managed to give the appropriate responses to market challenges related to new agricultural equipment. A plausible explanation for this success is given by the convergence of specialized (with the appropriate knowledge base) suppliers of machinery and the strong role played by research institutions.

Different types of networks characterize these countries, and in all of them there are firms operating at different levels of knowledge base, diverse linkages with clients and suppliers, disparities in the levels of information access and quality, and different economic scales (Bisang and Gutman, 2005). Recent studies[32] confirm that the main agro-food networks in the selected countries are efficient forms of business organization for achieving higher levels of innovation and having a competitive position in world markets (Farina, 2002). "Champion networks" like those created around Chilean Salmon, Brazilian Eucalyptus and Ethanol, and Argentinean Soya (Marín et al., 2009) contrast with others, where only weak linkages are established, for

[31] For instance regarding the wine sector in Chile, firms' perception is that universities and national research centers do not play a coordinated role, and more local industrial applied research is needed. (Moguillansky *et al*., 2006).

[32] ECLAC (1995), PROCISUR/IDB (2000), ECLAC (2002) and Giuliani et al. (2005)

instance due to mistrust (Moguillansky *et al*.,2006). Within weak networks there are greater difficulties to increase efficiency and to reduce transaction costs, to facilitate the process of innovation, to establish mechanisms for spreading risks -of natural and biological factors that characterize the sector-, and to lead to the formulation of strategies for the future evolution of the overall set of firms (Bisang and Gutman, 2005).

Institutions and norms affect this sector in a particular way: markets are highly influenced by institutions through international regulations (Bocchetto, 2001). Despite the three countries belong to Mercosur, they have not still built a common regulatory apparatus, such as antitrust policies, consumer protection laws, standards of health and hygiene requirements for food products, packing, and trade regulations (Boccheto, 2001; Trienekens and Zuurbier, 2008; Santana, 2009). Thus, more norms coordination and collective action supporting the sector seems to be indispensable.

Supra-national organizations (e.g. the Regional Fund for Agricultural Technology that promotes strategic agricultural research of relevance for the Latin American and Caribbean Region), international donors, and development agencies support firms in their access to technology and new products' development. An example of success can be found in the Chilean salmon industry due to the financial and technical support provided by international agencies during the first years of the industry (Maggi, 2007).

National R&D organizations (e.g. the Argentinean National Scientific and Technological Promotion Agency, the Brazilian Finep, and the Chilean Corfo) share the objectives of financing different extension services and acquisitions of new equipment. Indeed, institutional financial support is necessary, not only for investing in R&D but also for acquiring new equipment. As pointed by Farina (2001), Brazilian agro-food sector grew more quickly due to public support (minimum prices and by subsidized credit). Conversely, the lack of resources can result in failures (especially for small and medium firms). This is the case of the benefits of producing biocides in Argentina, which has been limited to large firms that hold the financial power to access foreign inputs and technology (Bisang *et.al*, 2005).

There are also regional programs such as the PROSAP (Programa de Servicios Agricolas Provinciales) in Mendoza (Argentina). It represents a good example of public financing services aiming to transfer knowledge and technology and to improve management practices to grape producers. The results obtained (e.g. increase of yields, increase of grape quality, etc.) demonstrate two interesting points: one is that the program has not been effective till it has not matched producers' needs. The second is that the positive results were conditioned by producers' characteristics (Cerdán-Infantes *et al*., 2008), in line with our proposition about the need of technological capabilities for benefiting from contextual conditions.

2.4. Firms within SSI and their innovative performance

Our empirical analysis is based on the SSI approach as useful tools in various respects: for a descriptive analysis of sectors; for a full understanding of their dynamics and transformations; for the identification of the factors affecting the performance, competitiveness, and innovation of firms and countries (Malerba, 2002); and for technology and innovation policy (it provides the identification of 'system failures' and the related variables which should be policy targets) (Malerba, 2005). However, rather than focusing on case studies (Malerba and Montobbio, 2004; Bell and Giuliani, 2005; Gu et al., 2009), this study put firms at the fulcrum of the empirical analysis, based on the General System Theory "the components are themselves systems of a next lower order" (Von Bertalanffy,1950, pp. 151). Firms are then our next lower order, and the ones which undertake innovation within systems. Indeed they are suppliers and users in the value chain that become relevant in the organization of innovative activities (Malerba, 2005), they build linkages with others agents (second building block), and are framed by specific institutional context (third building block). Focusing on this "new system", the second step is, to econometrically evaluate how these building blocks' patterns affect their propensity to innovate.

2.4.1. Firms' knowledge base

Firms build their own capabilities and innovate through their individual learning process. As already introduced in Part I, this process has two important elements that are extremely interrelated: existing knowledge base and intensity of effort[33] (Cohen

[33] The former element contributes to strengthen the latter through the spiral of technology learning. Cohen and Levinthal (1990, p.128) labeled Absorptive Capacity (AC) "the ability of a firm to recognize the value of new external information, assimilate it, and apply it to commercial ends". Regarding the second element, firms need to continuously undertake processes of local experimentation (Nelson and Winter, 1982) that are translated in *efforts* to assimilate external

and Levinthal, 1990). Success in manufacturing development depends on the creation and strengthening of indigenous capacities that are analyzed in this Part under the concept of Technological Capabilities (TCs) (Lall, 1996; Benavente et al. 1997; Bell and Giuliani, 2005). Linsu Kim (2001, p.9) defined TCs as the "ability to make effective use of technological knowledge in production, engineering and innovation…It also enables a firm to create new technologies and to develop new products and processes in response to their changing economic environment". They include also the creation of all the other Dynamic Capabilities (Eisenhardt and Martin, 2000; Teece *et al.*, 1997) needed for properly adapting, innovating and changing while the environment evolves.

Firms operate at different levels of TCs -within the SSI- and consequently have different innovation proneness. To measure the main patterns of TCs we introduce Lall's taxonomy (1992) that includes major firms' technical functions considering also the degree of complexity[34] or difficulty of them. Under this taxonomy there are then, investment, production, and linkages' capabilities[35]

Apart from the traditional mentioned technical functions, we are interested also in analyzing education, skills, and training, at the firm level. Indeed, these elements enhance people's ability to receive, decode and understand information and this is important for performing or learning to perform many jobs (Nelson and Phelps, 1966). Notable literature contributions have been given by different authors in this sense. Criscuolo and Narula (2002) emphasize the role of human capital –that means qualified human resources-: they are essential in monitoring the evolution of external knowledge and in evaluating the relevance of technologies that should be integrated into productive activities.

2.4.2. Linkages

knowledge. The nature and degree of *efforts* is not uniform among firms and sectors: different activities have different requirements for capabilities acquisition (Lall, 1992).

[34]Depending on the degree of complexity, TCs can be separated in basic (experience-based routines), intermediate (adaptative or duplicative), and innovative risky (research based) functions. Among them, there are also processes of sequences and cumulativeness. However in this work we do not explore "degrees of complexity". Working only with one year, it may be difficult to judge a priori whether a particular function is simple or complex (Teitel, 1984)

[35] For a description of each category of capabilities see page 27.

Concerning networks' building block, firms systematically diverge in the extent to which they build external collaborative linkages[36], and their specific attributes affect the value that firms derives from such relationships (Intarakumnerd, P., 2011; Teece, 1986; Nelson, 1991). To incorporate external technology is not a straightforward process, even at an imitative stage, it becomes difficult to convert knowledge, and special indigenous skills are needed to allow firms to absorb and adapt external knowledge.

The network concept is used in several studies for analyzing the horizontal and the vertical relationships among manufacturing firms (Henderson *et al.*, 2002; Raynolds, 2004). For the purpose of our work, we focus on one aspect of firms' relationships within networks: the vertical linkages, and in particular firms' use of domestic or foreign inputs, and foreign technology. We analyze functions related to the use of foreign technology, both type embodied (inputs) and non-embodied (licenses), to understand how much firms rely on innovative technology from outside the country. External linkages are highly fruitful: they allow firms to be aware of more technologically advanced knowledge. However, if firms are mostly focused on foreign relationships, they also reflect weak technology support from the national innovation system (Muchie and van Baskaran, 2009) for its industries.

2.4.3. Institutions' perception

Firms are embedded within a national regulatory framework that can reinforce or hinder their innovative activity. Labor market structures can foster stable employment relationships, facilitating learning by doing and stimulating employers' incentives to train employees (Asheim and Gertler, 2006). Indeed under divergent set of national institutions governing labor market and corporate governance, the kind of relationships between economic actors can very different (Christopherson, 2002). More closed, rigid and hierarchical systems can underperform other systems that are more open and flexible (Saxenian, 1994). We concentrate our attention over firms' perception about institutions: in particular we are interested in administrative obstacles, labor conditions and environmental restrictions.

[36] Even if linkages are a category of TCs (see Lall's taxonomy in section 4.1.), due to their importance we treat them as part of the networks' building block.

2.4.4. Firms' innovative behaviour

Innovation is considered both, a demonstration of the firms' most complex level of TCs, and also an output, reflecting firms' technological achievements. Consequently, as the process of building TCs is cumulative and path dependent (from basic to more complex TCs), we assume that product and process innovation are possible only if firms have accumulated and upgraded their TCs.

Even if the innovation *per-se* is undertaken by the single firm, it is an actor's decision that has systemic characteristics. Literature and evidence agree that innovation is a cumulative and social process, involving interactions among people and information flows (Nelson, 1991). Thus, it reflect also "a collective learning and socially embedded process that is crucially dependent on tacit knowledge and untraded interdependencies" (Crescenzi, 2005, p.472) that may not be simply duplicated.

We are interested also in analyzing the role of firms' size that frequently exerts a great influence over their proneness to innovate: large firms have facilitated access to finance, scale economies, and better organizations structures (Mairesse and Mohnen, 2002). In these sense, linkages and networks between enterprises can be an option to go beyond firms' size limits.

However, in certain technologies large firms do the bulk of innovative activities while in others, small firms are also quite active (Malerba and Orsenigo, 1996). Thus, size advantages and disadvantages strongly depend on sectors (Pavitt *et al*., 1987; Rothwell and Dodgson, 1994). In the following paragraphs we aim to empirically analyze the importance of size for innovation in this SSI.

2.5. The model and the results of the analysis

2.5.1. Data

The empirical part is based on data from the World Bank Investment Climate Survey. The surveys were conducted on a sample[37] of representative enterprises in Argentina

[37] The samples were selected using a stratified random method: all population units are grouped within homogeneous groups and simple random samples are selected within each group. This method allows computing estimates for each of the strata with a specified level of precision while population estimates

(2006), Brazil[38] (2003), and Chile (2006). The samples of firms were stratified by size, sectors, and location. The three countries' data were matched to a standard set of questions, then the surveys become highly comparable and the format allows cross-country comparisons and analysis.

These surveys covered mainly manufacturing and certain services for registered firms. Starting from micro data for analyzing sectors, this work considers the two digits ISIC[39] level of aggregation (the one selected by the World Bank in its Investments Climate Survey) as appropriate level of analysis, focusing only on Food Processing manufacturing enterprises.

Regarding size, the total employment is used to divide firms in small (less than 20 employees), medium (20-99 employees), and large (more than 100 employees) (see Table 8). For stratification purposes, the number of employees was defined on the basis of reported permanent, full time workers. Although the surveys were not conceived for analyzing TCs, we found in them some useful questions for evaluating them under a SSI approach.

Table 8. Survey's composition regarding size within Food Processing Sector

	Argentina	Brazil	Chile
Number of firms	167 (100)	129 (100)	160 (100)
Small firms (5-19 employees)	100 (60)	17 (13)	66 (41)
Medium firms (20-99 employees)	50 (30)	45 (35)	59 (37)
Large firms (> 100 employees)	17 (10)	67 (52)	35 (22)

Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003.

Note: Percentages in parentheses

The choice of the proxies for empirically measuring the agents' knowledge base, linkages and institutions' perception is determined according the Table 9:

can also be estimated by properly weighting individual observations. Weights take care of the varying probabilities of selection across different strata.

38 We use the 2003 Brazilian survey because, unfortunately, the 2009 World Bank Investment Climate Survey does not give information about R&D investments, innovation in product, and process.

39 ISIC is a standard classification of economic activities, correspondences with Central Product Classification (CPC) and Standard International Trade Classification Revision 3 (SITC). The categories of ISIC, at the most detailed level (classes), are delineated according to what is, in most countries, the customary combination of activities described in statistical units (activity units). The groups and divisions, and the successively broader levels of classification, combine the statistical units according to the character, technology, organization and financing of production. To limit the surveys to the formal economy, the sample frame for each country should only include establishments with five (5) or more employees. Fully government owned firms are excluded (www.web.worldbank.org)

Table 9. List of variables and definitions

Firms' knowledge base (First Building Block)
Education Level: average education attainment of a typical production worker. The levels vary between 1 (as the lower) and 4 (as the higher) level.
Skilled production workers: considers the percentage of skilled workers -that have some special knowledge or ability in their work- among the total production workers.
Training Programs: a dummy variable that reflects if the firm has programs that have a structured and defined curriculum. May include classroom work, seminars, lectures, workshops, and demonstrations.
Buy new equipment and machinery (USD)[40]: reflects the annual expenditure on purchase of machinery, vehicles, and equipment.
Quality: is a dummy variable considering if the firm is or is not quality certified, but only with internationally recognized certifications (ISO and HACCP that is specifically for food, but not for seafood and juices)
Investment in R&D (USD): this variable takes account of how much the sample firms invest in in-house R&D or contracting with a third party (see Note 18)
Firms' linkages (Second Building Block)
Percent of inputs/supplies from domestic companies: considers the percent of inputs and supplies that a firm receives from domestic companies.
Percent of inputs/supplies from foreign companies: consider the percent of inputs and supplies that a firm receives from foreign companies.
Technology from foreign companies: is a dummy that takes value 1 or 0; considering if the firm receives or does not receive technology from foreign companies.
Firms' perception of institutions (Third Building Block)
Administrative Conditions: is a variable that represents the level of obstacles faced by the firms when dealing with licensing and permits, and also percent of total senior management's time dealing with government regulations, inspections, and bureaucracy.
Labor Conditions: considers firms' perception about the availability of educated labor force and labor regulation.
Environmental restrictions: reflects the degree of obstacles due to environmental restrictions.

2.5.2. Principal Component Analysis

[40] The variable was originally expressed in local currency but was translated into dollars (USD). For Argentina and Chile is the average interbank rate 2005 and for Brazil is the average interbank rate 2003. (http://www.oanda.com/lang/es/currency/historical-rates)

Under a SSI framework, we link the firms' knowledge base (first building block), linkages (second building block), and institutions (third building block), and perform a Principal Component Analysis (PCA) with two main scopes. The first one is referred to parsimony. This means to provide a synthetic index that reduces a multivariate situation in a reduced dimensionality while retaining most of the information of each SSI's building block. The second one means to serve as basis, for imposing a structure to the domain (Dunteman, 1989), that is to identify firms' shared patterns within the Food Processing SSI as well as the presence of outliers among the three countries.

There are many different ways to determine the optimum number of principal components[41] to retain, which have the potential to represent the data variability with a criterion of "efficiency". How many and which principal components to retain depend, on the goals of the analysis (Dunteman, 1989). As we have a small number of components and simply want to describe the variable set, for the first building block we elect to stop on the third largest one, and for the third building block we stop on the second largest one.

Focusing on firms, we aim to evaluate their main knowledge base (first building block). Our analysis follows Lall's taxonomy of TCs, but only includes production capabilities (no information was available for investment capabilities in the surveys), for the first building block. Linkages capabilities are on the one hand, a TCs (Lall, 1992), and on the other hand, (under the systemic view) they are an overlapping area between the first and second building blocks. Due to their importance, as stated previously, we evaluate them as an evidence of the second building block. The analysis is replicated for the institutions building block considering some interesting characteristics.

[41] Edward J. Jackson (1991) presents in his book "A User's guide to Principal Components" several ways of deciding "When to stop?" -from significance tests to graphical procedure.

Table 10. PCA: principal components' coefficients. First building block

	Argentina			Brazil			Chile		
Variable	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
Education	0.06	0.40	0.87	0.29	0.72	0.10	0.34	-0.24	0.69
Skilled	0.57	-0.28	-0.01	0.46	-0.31	-0.43	0.47	-0.01	0.30
Training	0.21	0.66	-0.15	0.50	0.36	0.24	0.43	-0.46	-0.32
Quality	0.27	0.52	-0.44	0.38	-0.06	-0.13	0.48	-0.25	-0.44
R&D	0.47	-0.14	0.15	0.16	-0.38	0.85	0.39	0.55	0.19
New Equip	0.56	-0.22	0.02	0.53	-0.32	-0.08	0.31	0.60	-0.32
Proportion	0.40	0.22	0.16	0.26	0.18	0.17	0.33	0.19	0.16
Cumulative	0.40	0.62	0.78	0.26	0.44	0.61	0.33	0.53	0.69

Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

We obtain the same number of Principal Components (PC) and variables, which prove that there are no exact linear dependencies among the variables. The first PC explains only between the 28% and 38% of the total variance of the six components – depending on the country-. The variances accounted increases substantially by retaining the third[42] PC (Appendix C), thus we retain three PC to have the variables adequately represented by the PC.

The coefficients for the first PC, within the first building block of the SSI, in the three countries are all positive at different sizes (see Table 10). This highlights that firms that are concerned with one of the patterns of this building block are also interested in the other or others, at different levels. The size of the correlations (loadings) for a particular component reflects the importance of the component in explaining our blocks.

There is a common pattern on the three countries: the coefficients assign a large load to investment in skilled workers, confirming that firms are mostly concentrated in basic TCs. In Argentina and Brazil, the coefficients assign an important load to expenditures in new equipment, reflecting that firms require increasing amounts of fixed capital in this SSI, as new forms of production rise the technical requirements (Farina, 2001; Bisang and Gutman, 2005; Anllo and Suarez, 2008). Other variables

[42] If we examine the sum of squares of the loadings of the first three PC, some variables have a substantial proportion of their variance explained by the largest three PC. This is the case of Education in Argentina and R&D in Brazil, which have the 90% of their variance accounted in the first three PC. In Chile the Education variables has the highest explained variance but with only the 64%.

representing basic and intermediate capabilities take relevance: quality certification in Chile, and training in Brazil. It is also interesting to observe the important loads that investment have in R&D in Argentina: under a PCA it should be interpreted that firms that spend in new equipment, and skills, invest also in R&D in these countries.

Regarding firms' linkages (second SSI building block) there is a linear relationship among two variables: inputs from domestic and foreign origin. Thus, the knowledge of one of them helps to determine the other remainder variable without error. Indeed these variables are complementary and sum up one: firms classified their one hundred percent inputs between having domestic and foreign origins. With only two remaining variables within this building block the PCA analysis could seem redundant[43].

Firms' perception about their main development obstacles importance of institutions (third building block) is highlighted here by some selected variables, which obviously represent only a part of the complex dimension of institutions. Nevertheless, they point out some interesting issues regarding administrative and environmental obstacles, and labor conditions that sometimes act as crucial determining behind firms' innovative performance.

Table 11. PCA: principal components' coefficients. Third building block

	Argentina		Brazil		Chile	
Variable	PC1	PC2	PC1	PC2	PC1	PC2
Administrative Obstacles	0.60	-0.49	0.65	-0.32	0.58	-0.46
Labor Conditions	0.64	-0.19	0.67	-0.20	0.59	-0.33
Environmental Restrictions	0.49	0.85	0.37	0.92	0.56	0.83
Proportion	0.47	0.29	0.42	0.32	0.53	0.25
Cumulative	0.47	0.76	0.42	0.74	0.53	0.77

Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

In Table 11. the PCA's coefficients assign high weights to obstacles faced by firms for operations, due to administrative and environmental restrictions, and also firms' perception about labor conditions, in Argentina and Brazil. These positive and high

[43] Analyzing the two remaining variables, Inputs from Foreign Origin and Foreign Technology, the coefficients for the first are both 0,71 and for second principal components -0,71 and 0.71. With only two variables there are only two PC, that completely account for the variation in the two variables. Graphically, the first PC forms a 45 degree angle with the ordinate axes irrespective of the size of the correlation as long as the correlation is not zero (Dunteman, 1989).

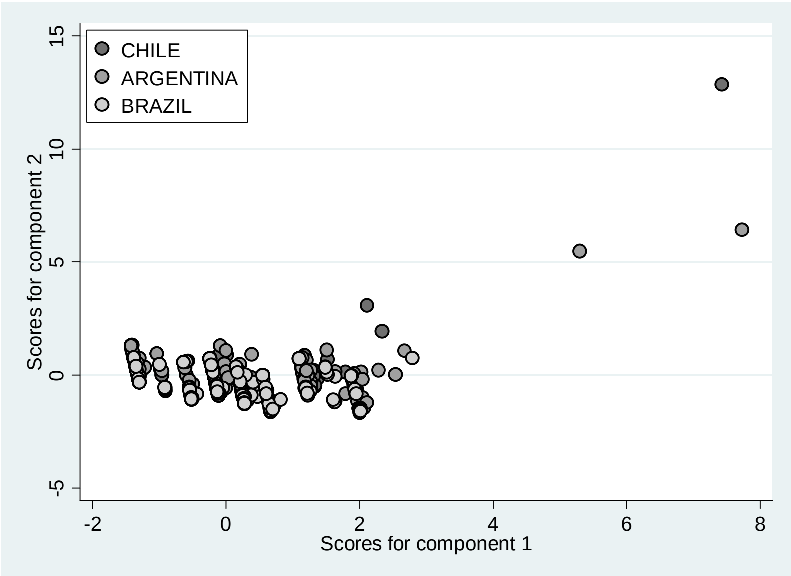
weights mean, on the one hand heavy difficulties for the enterprises' development and important obstacles to innovate and one the other hand the availability of educated labor force and labor regulation. Concerning Chile, the coefficients are again positive and have almost the same loadings for the three analyzed variables. This means that each variable is equally represented in the linear composite, and that manufacturing firms give the same importance to this two different types of indicators: the administrative obstacles and the environmental restrictions, and the labor conditions. Further research is needed to understand in which way regulations may foster a more homogeneous and sustainable[44] SSI development.

Under a comparative view, we inquire about shared building blocks' characteristics between the three studied countries. We merge countries' datasets into one, perform the PCA for firms -related to each building block-, and plot their scores in a two dimensional space. A major advantage of PCA is that, if the two PC account for a substantial portion of the total variation, it is possible to approximate the distribution of the observations in the variable space by plotting the PC scores (Dunteman, 1998). PCA allow then, to lower the original dimensional space into a two dimensional subspace using the first two[45] PC as coordinate axes. The PCA analysis permits also to visually search for clusters and outliers between firms.

[44] For an extensive analysis of the impact of technology on sustainable agro-food processing development see Ekboir (2003).

[45] For the first building block we stopped in the third PC, but as the data points defining PCs are most unlikely to define a smooth surface, any three dimension view is unlikely to be much good in any case.

Graph 3. First Building Block - Scores from PC1 and PC2 in Argentina, Brazil and Chile



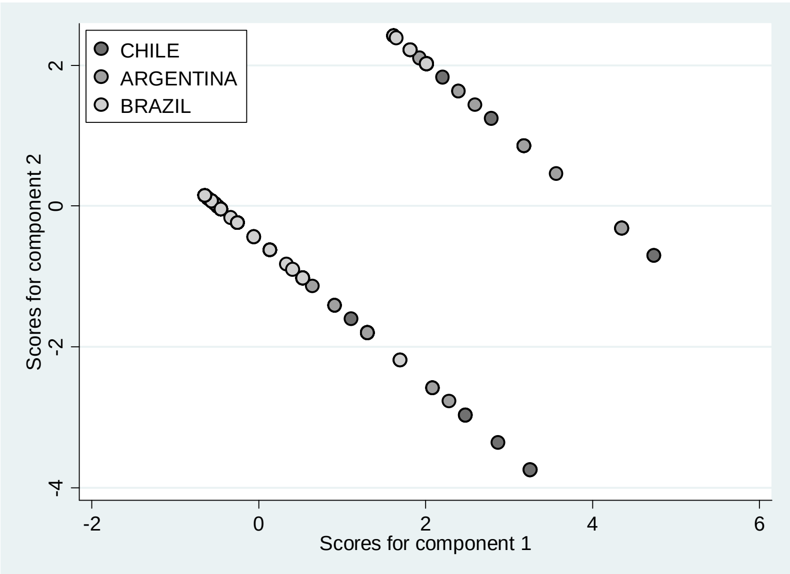
Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

In Graph. 3 we observe that the three countries' firms have similar characteristics[46] regarding the knowledge base building block. Firms from the three countries are found close to each other, revealing shared patterns of TCs. There are only few firms that can be considered outlying observations, as they lie at a considerable distance from the rest of the firms. Since the skilled production workers and new equipment variables have high loadings in Argentina, and skilled production workers and quality in Chile, it is expected that these few outlying firms –two from Chile and one from Argentina- had high values on one or both variables, depending on the country. The evidence again confirms the hypothesis that firms invest and put their efforts in the most basic TCs, in particular new equipment and skilled production workers, in these three SSI. This strategy is just a starting point for achieving more complex capabilities, and only sustained by the other pillars of the system (networks and institutions) may allow firms to innovate.

[46] With the caveat that for the first building block we are only considering only two and not three PC –as in the analytical analysis- for the graphic analysis, this plot remains a good approximation of the original space.

We perform PCA and graphically analyze the results for the second building block and compare the three countries' position regarding the use of foreign technology in both types embodied (inputs) or non-embodied (licenses).

Graph 4. Second Building Block - Scores from PC1 and PC2 in Argentina, Brazil and Chile

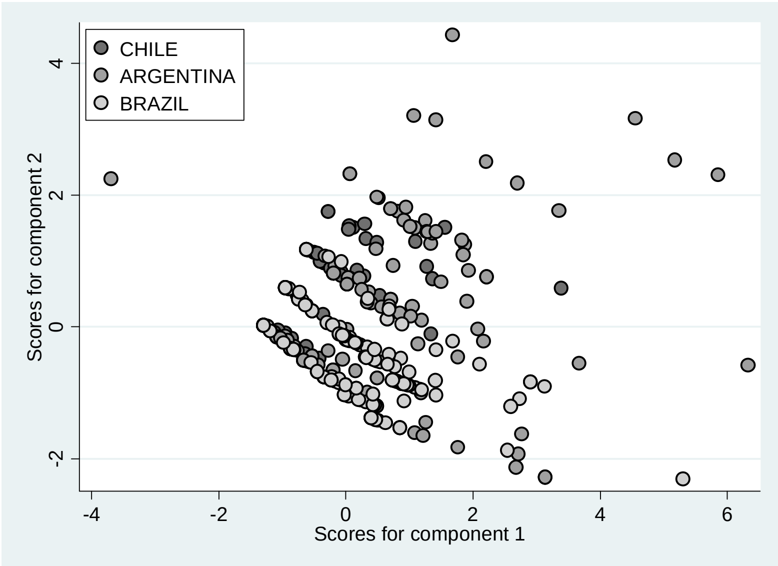


Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

Most of Brazilian firms are found in the left area of the Graph 4. with low loads of the variables, while Chilean ones are found on the right extreme. With the caveat that, the availability of variables constrains our analysis only to some limited vertical relationships, and the consciousness that there are also many other vertical and horizontal interesting linkages to be analyzed, we extract some conclusions about this sector. It is that firms do not behave in the same way regarding their foreign linkages in the three countries: Brazilian firms tend to rely frequently on national technology (Ekboir, 2003; Bisang and Gutman, 2005; Marin et. al, 2009). As the acquisition of technology from external sources can be seen in two ways, that is the intention of being at the technological frontier level, or the weakness of the national system of innovation, specific cases should be analysed to understand the motivations underlying these options.

In Graph 5. we examine firms' perception about institutions (the third building block), again under a two-dimensional representation, expecting the plot of the scores of the first two PC can show shared patterns and possibly the presence of outliers. In the survey, questions are posed to firms to identify obstacles and advantages for operating. Then, the presence of high loads should be interpreted as good labor conditions, administrative obstacles, or environmental restrictions.

Graph 5. Third Building Block - Scores from PC1 and PC2 in Argentina, Brazil and Chile



Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

There is a homogeneous clump of observations among the three countries, with short distances between them, coexisting with other observations that are evenly spread throughout the variable space. Most of the firms from the three countries are found very near to each other reflecting similar perceptions about the institutions. However, some firms are relatively far from each other, and there are also few outliers situated in the right side, meaning very important loads of the first PC. In the case of Argentina and Brazil, high loadings should be related to administrative difficulties and labor conditions, while in Chile high loadings should be homogeneously related to the three variables.

2.5.3. Firms' innovative behavior in the Food Processing sector

As expected, size matters for innovation in the Food Processing Sector (with the exception of Brazil, where medium firms are the leaders in innovation): the largest the firms, the more likely they innovate (see Table 12). A very interesting finding is that more than the 50% of medium firms introduce product and process innovation in the three countries, and more than the 50% of small Argentinean and Brazilian firms, introduce innovations, too (Chilean small firms are the less innovative among the group).

In the three countries, when small firms innovate in product, they innovate in process as well. Medium firms tend to innovate more in product, except from Argentinean firms (where the same number of firms innovate in process and in product). In Argentina, large firms achieve more product innovation, while in Chile, they achieve more process innovation. Brazilian large firms behave as small ones: when they introduce product innovation they introduce also process innovation.

Table 12. Innovative firms in the Food Processing Sector

	Argentina		Brazil		Chile	
Firms' size	In Product	In Process	In Product	In Process	In Product	In Process
Small	65 (65)	63(63)	9(53)	9(53)	27(41)	28(42)
Medium	35(70)	35(70)	30(67)	31(59)	40(68)	32(54)
Large	16(94)	12(71)	39(58)	39(58)	25(71)	28(80)
Total	116 (69)	110(66)	78(60)	79(61)	92(57)	88 (55)

Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003.

Note: Percentages in parentheses

2.6. The Econometric Analysis

Our purpose now is to enquire how the knowledge base, the networks, and the institutions influence the probability to introduce new products and new processes within the Food Processing SSI. Each building block has been analyzed separately; now the three of them are jointly evaluated to see how the whole system behaves regarding innovation in each country.

The likelihood function is posited to evaluate the binary outcome variable and is examined under the Probit model, as the dependent variables assume values 0 or 1. We expect to investigate the relationship between the response probability and the explanatory variables:

$$P(Y=1|X) = G(\beta_0 + \beta_1 X_1 + \ldots\ldots\ldots\ldots + \beta_k X_k) = G(\beta_0 + X_i \beta)$$

where G is a function taking on values between 0 and 1. In our case G is the standard normal cumulative distribution function, which is expressed in Equation (1) and (2) to describe the general specification:

$$P\ (Y_{1i} = 1) = \Phi\ (X_i\ \beta) \qquad (1)$$

$$P\ (Y_{2i} = 1) = \Phi\ (X_i\ \beta) \qquad (2)$$

where $Y_{1i} = 1$ indicates that the firm i introduced new or significantly improved products and $Y_{2i} = 1$ refers to the fact that firm i introduced new or significantly improved processes. On the right side of the equation there is Φ: the standard normal density function of firms' explanatory variables X_i representing the three building blocks.

The econometrical models are run, and in Table 13. the product and process innovation are evaluated over the variables of the three SSI's building blocks. But there is a potential problem: the presence of heteroscedasticity makes some care necessary in interpreting the coefficients (Greene, 2002). Thus, we correct for heteroschedasticity running also the Heterogeneous Choice Model [47](Williams, 2010) and we obtain similar coefficients.

As stated before, innovation is considered as a complex type of TCs (Lall, 1992), but it is also an output of the process of building TCs (Freeman, 1995). The goal here is to consider it as an output, sourced by the selected variables, representing the three SSI building blocks, and to evaluate their joint significance over firms' innovative performance.

[47] Since coefficients are always scaled (so that the residual variance is the same no matter what variables are in the model), the scaling of coefficients will differ across groups if the residual variances are different, making cross-group comparisons of effects invalid. The Heterogeneous Choice Model provides a means for dealing with these problems by simultaneously estimating two equations: one for the determinants of the outcome, or choice, and another for the determinants of the residual variance" (Williams, 2010, p. 4)

Table 13. Probit Model. Innovation in Product and in Process with the selected variables for each country

	Argentina		Brazil		Chile	
	In Product	In Process	In Product	In Process	In Product	In Process
Knowledge Base						
Education	0.3679	-0.1235	0.0192***	-0.0024	2.4976	-1.3444
Skilled Pr. Employees	0.4654	-0.0004	-0.2595	0.0530	0.1307	0.2742
Training	0.5416**	0.2919	0.1010	0.5345**	1.0148***	1.3751***
Quality	0.1799	0.0281	-0.2266	-0.1545	0.2676	0.3618
R&D	0.0000	0.0000*	0.0000	0.0000	0.0000	0.0000
New Equipment	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Linkages						
Foreign inputs	-0.4276	-0.3055	0.0158	0.0177	0.0514	-0.0405
Foreign technology	-0.0123*	-0.0040	0.4850	-0.1198	-0.0008	-0.0054
Institution's perception						
Administrative Conditions	-0.0015	0.0024	0.0048	0.0147	0.0064	0.0045
Labor Conditions	0.0344	0.0211	0.0556*	-0.0348	0.0041	-0.0156
Environmental restrictions	0.0400	-0.0021	0.2555	0.2968	-0.1510	-0.1520
Log-Likelihood Value	-77.1934	-85.5143	-74.6600	-71.9957	-76.1083	-74.9021
Pseudo R-Squared[48]	0.1258	0.0673	0.1111	0.1120	0.1944	0.2111

Source: World Bank Investment Climate Survey. Argentina and Chile 2006; Brazil, 2003

Note: the dependent variables are Innovation in Product and Innovation in Process. * significant at 10%, ** significant at 5%, *** significant at 1%

In Table 13, regarding the knowledge base, the basic TCs education, increases the probability to introduce product innovation, while the variable training, increases the probability to introduce process innovation in Brazil. The former variable can reflect the fact that the sector is becoming always more "science-based" where education is a key of success as it allows "the symbiosis between traditional industries and science" (Lundvall, 1985, pp. 30). The variable training also increases the probability of introducing product innovation in Argentina, and both types of innovation in Chile. This fact is in line with the idea that knowledge is created less in a deductive process or through abstraction, but more often in an inductive process of testing, experimentation, thus training allowing more efficiency and incremental change in the form of new processes (Asheim and Coenen, 2005). No other variables positively and significantly increase the probability to innovate in the three countries.

[48] Based on the Log-likelihoods we compute the pseudo *R*-squared and obtain low values. Goodness of fit is usually less important than interpreting the effects of the explanatory variables (Wooldridge, 2006), we then concentrate our analysis on the latter objective.

The variables related to linkages follow the same fashion: they do not increase the probability to innovate. Networks -only considered through this limited approach of vertical integration- seem to be not strong enough to foster innovation.

Considering the institutions building block, with the boundaries of the available information, there is only one significant positive coefficient for the probability of introducing new products in Brazil. It is related to the variable labor conditions that in this case are seen as opportunities for innovating. The explanation may be found in some Brazilian labor policies (Cella dall Chiavon, 2003) that are probably perceived by firms, as adequate labor measures for promoting innovation.

Our model includes firms' variables concerning knowledge base, linkages and institutions. Nevertheless we make a final prove of the advantages of including the whole systems' variables. We evaluate if adding the second and third groups of variables as predictors (together and not just individually) lead us to obtain a statistically significant improvement in model fit. We perform the Likelihood Ratio Tests (LR) test. Thus, two models need to be run: one model has a set of variables, and the second model has all the parameters from the first one, plus the new variables, belonging to the other groups. When including only the variables of the second group to the first one, no improvements in the fit of the model are made. Nevertheless, when adding the third group's variables, we obtain the expected results: the LR test compares the Log Likelihoods of the two models, with and without the third group's variables, and confirms that the difference is statistically significant.

Table 14. T-statistics and p-values for adding the third building block variables

	Argentina		Brazil		Chile	
	In Product	In Process	In Product	In Process	In Product	In Process
T-Statistics	58.1847	58.7926	18.5929	19.8093	34.1608	36.6404
P-Values	0.0000	0.0000	0.0009	0.0005	0.0000	0.0000

In Table 14. we show the T-Statistics and P-Values. The less restrictive model (the one with the institutions' variables) fits the data significantly better than the more restrictive one. The results confirm that the proposed empirical model, including the three building blocks together, is the most appropriate one.

2.7. Concluding remarks

In this Part, we have studied the Food Processing Sector under an evolutionary and systemic approach, providing a descriptive analysis of the sector which allowed identifying some factors affecting innovative performance within the SSI. The sector has been theoretically portrayed through the three main building blocks of the SSI. For the purpose of our study, we redefined the first building block as "agents", and it has become the cornerstone of our research for understanding the systemic aspects that promote innovation within the Food Processing SSI.

The sector is characterized by the coexistence of mass/standardized and differentiated/ technologically sophisticated production. There is, however, a rising demand of quality and safety in food products, as well as differentiation and sophistication (a shift from traditionally mass/standard products towards differentiated products and niches). The great challenge for the sector is, therefore, innovation. It needs to occur within a system composed of a set of interacting agents (firms and non-firm organizations), networks, and institutions.

Analytical and synthetic knowledge, tacit and codified, characterize the knowledge base of the different industries within this SSI. Thus, depending on them, more equipment, training, skills, R&D, and other technological capabilities are needed, in the process of learning by doing, using, or interacting. No preferences about which aspect should be emphasized can be assumed without a careful analysis of the specific case and without a systemic consideration.

Linkages with other firms and non-firms agents (R&D centers, universities, etc) for building strong networks are always more important for innovation. As a natural consequence, public R&D plays a fundamental role, in both basic and applied research. Institutions frame these relationships, providing resources, rules, and flexibility or hampering the agents' mission within the SSI.

With this theoretical basis, the present Part focuses on the Food Processing SSI in the selected countries. Different literature studies highlight some shared patterns: the interest on investing in new equipment, the crucial role of non-firms agents (research centers, universities and consumers), and low public R&D investments. Evidence of successful cases is found when strong relationships are created within networks and when adequate technological capabilities are present in firms. Moreover, the results are boosted when public resources are strategically assigned. The intuition behind these findings is that, the closer the agents work together (firms, consumers and research centers) the better results they achieve. The cooperation between firms and research centers, regarding analytical and synthetic knowledge can result in widespread innovation.

We deepen the analysis focusing on firms as the main actors and generators of innovation. Relying on the systemic approach, we analyze their knowledge base, their linkages and their perception about institutions. Empirically working with the World Bank Investment Climate Surveys for each country, we perform a PCA starting with firms' knowledge base (fundamental instrument to face technological change) and studying it under the Technological Capabilities (TCs) approach[49]. As expected, the results show a common pattern in the three countries; large load to investment in basic capabilities such as skilled workers, and also to other basic capabilities (new equipment in Argentina, training in Brazil and quality certification in Chile). These findings can be seen a good starting point, but not as a panacea: if firms continue operating without increasing their knowledge base's complexity, they will probably face difficulties to interact with other agents and to take advantages of the system's opportunities, lagging behind in technological changes.

The graphical PCA gives a comparative picture of the three countries' SSI. Many similarities between them highlight shared patterns of firms' behavior and contextual conditions. Concerning firms' vertical relationships for the acquisition of embodied and non embodied technology, Argentina and Chile rely more on foreign technology than Brazil. There is a more homogenous behavior regarding institutions in the three countries: most of the firms give high loads to all the variables.

The empirical research finally delves into innovation. We first gave an approach on firms' innovative proneness, finding that large firms (in Argentina and Chile) and mediums firms (in Brazil) are the leading innovators. Then, we econometrically analyzed the influence of firms' knowledge base patterns, linkages and institutions' perception over product and process innovation. The empirical results, focused on firms, confirm that only few SSI variables have a positive impact on innovation.

Connecting with the theoretical with the empirical part, the evidence gives the idea that firms are focused on basic technological capabilities and depend on foreign technology, exerting difficulties to innovate. Nevertheless, successful examples highlight that, when indigenous efforts are undertaken, strong linkages are created,

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[49] We are following the same theoretical basis from Part I but using different methodology

and are accompanied by helpful institutions, enabling firms to introduce new products and new processes.

Our first caveat, regarding analyzing such a wide sector with limited information, is justified through this Part's acknowledgement that we have provided only an initial overview at the SSI. We expect that this still gives a good platform to study in-depth this system by raising some Food SSI characteristics and disentangling their three main building blocks. Our second caveat is related to the limited information available in these surveys for studying our building blocks. We constrain our study only to specific types of linkages and some interesting aspects of institutions. Nevertheless, they allow us to obtain some important findings about firms' relationships with their environment.

This study expects to make a conceptual and holistic contribution to the Food Processing SSI and an empirical analysis of the system through the vision of firms. With some expected and unexpected findings, the studied scenario suggests that, even if innovation is generated by individual firms in the three countries, their single efforts are frequently not enough when the surrounding system is not in tune with their requirements. Not only formal rules, but also informal relationships, need to be fostered within this system. The present Part should stimulate further research, including, case studies and aggregate statistical measures of the different subsectors, for a better understanding of their underlying realities.

Appendix C.

Table C1. Principal Component Analysis: Eigenvectors. Food SSI. First Building Block (Argentina)

Variables	PC1	PC2	PC3	PC4	PC5	PC6
Education	0.0602	0.4012	0.8679	0.1411	0.2359	0.0817
Skilled	0.5692	-0.2795	-0.01	-0.1707	0.2193	0.7215
Training	0.213	0.661	-0.1474	-0.6617	-0.2413	0.0028
Quality	0.2722	0.5249	-0.4441	0.6013	0.3009	0.0332
R&D	0.4658	-0.1355	0.15	0.5689	-0.6404	-0.0919
New Equip	0.5586	-0.2249	0.0182	-0.2509	0.333	-0.6806

Table C2. Principal Component Analysis: Eigenvectors. Food SSI. Third Building Block (Argentina)

Variables	PC1	PC2	PC3
Administrative Obstacles	0.5974	-0.487	0.6372
Labor Difficulties	0.6368	-0.1949	-0.746
Environmental Restrictions	0.4875	0.8514	0.1937

Table C3.Principal Component Analysis: Eigenvectors. Food SSI. First Building Block (Brazil)

Variables	PC1	PC2	PC3	PC4	PC5	PC6
Education	0.2922	0.7234	0.0998	-0.3212	0.3483	0.3961
Skilled	0.4607	-0.3122	-0.4281	-0.3177	-0.4365	0.4643
Training	0.5035	0.3603	0.2435	0.1706	-0.5696	-0.4516
Quality	0.3829	-0.0553	-0.1308	0.8248	0.2713	0.2817
R&D	0.1608	-0.3826	0.851	-0.0706	-0.006	0.3138
New Equip	0.5257	-0.3162	-0.0786	-0.2856	0.5386	-0.4957

Table C4.Principal Component Analysis: Eigenvectors. Food SSI. Third Building Block (Brazil)

Variable	PC1	PC2	PC3
Adminin Obstacles	0.6473	-0.3226	0.6906
Labour Difficulties	0.6651	-0.2037	-0.7185
Environmental Restrictions	0.3724	0.9244	0.0827

Table C5.Principal Component Analysis: Eigenvectors. Food SSI. First Building Block (Chile)

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Education	0.3389	-0.24	0.6871	0.4971	0.1301	0.3022
Skilled	0.4676	-0.0121	0.3015	-0.7011	0.3817	-0.2304
Training	0.4303	-0.4596	-0.3186	0.3244	-0.0722	-0.6258
Quality	0.4771	-0.2542	-0.4411	-0.1905	-0.1939	0.6628
R&D	0.3934	0.5494	0.1914	0.0046	-0.6964	-0.1476
New Equip	0.3145	0.6038	-0.3231	0.3461	0.5564	0.0525

Table C6.Principal Component Analysis: Eigenvectors. Food SSI. Third Building Block (Chile)

Variable	PC1	PC2	PC3
Adminin Obstacles	0.5835	-0.4554	0.6724
Labour Difficulties	0.5882	-0.3338	-0.7366
Environmental Restrictions	0.5599	0.8253	0.0731

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PART III: R&D AND TECHNOLOGICAL CAPABILITIES AS DRIVERS OF INNOVATION IN BRAZIL

3.1. Introduction

Brazilian industrial performance has motivated extreme interest among researchers, representing a leading industrial case among emerging countries. Its industrialization process has not been trivial and has left a wide and diversified industrial base, yet not completely competitive for the local and the external market. From the agro-exporter profile, Brazil moved over the years into a diversified industrialized one, demonstrating the ability to develop different industrial strategies, facilitated by specific development policies (protectionism, public subsidies, completely state owned companies or companies with state participation, etc.), by the attraction of foreign direct investments and, most importantly, by innovation.

There is strong evidence that Brazilian public and private investments in R&D are still scant. On the other hand, it is well known that R&D country industries lagging behind the productivity and technological frontier catch up particularly fast if they invest heavily in R&D (Griffith *et al*., 2004). Furthermore, it should be an extremely important strategic decision for governments to decide between promoting more private and public R&D based on the expected social and private rates[50] of return to R&D (Bloom *et al*., 2008).

When firms invest in R&D, they contribute to their absorptive capacity development. Thus, “prior knowledge” allows them to “recognize”, to assimilate, and to exploit new knowledge available in the system of innovation. R&D and other technological capabilities provide two potential complementary sources for achieving innovation. We aim to empirically examine whether R&D can increase the probability to innovate, given a specific level of technological capabilities, and whether neighbors R&D investments have a direct effect over innovation, as our selected firm performance indicator. The novelty of this study relies in splitting R&D from the other technological capabilities with two main scopes: R&D influence over its owners’ firm innovation as well as its influence over owner firm’s neighbors.

[50] Bloom *et al.* (2008) develop a methodology for deriving the social and private rates of return to R&D, measured in terms of the output gains generated by a marginal increase in R&D.

This Part connects two existing literatures on the innovation debate, by extending the conventional Schumpeterian formalization ideas about the sequential linear innovation model, looking at innovation no more as a linear, but as a more complex process. Under an evolutionary vision[51], also firms' peculiar nature and other technological capabilities (indigenous knowledge, competencies, and specific characteristics) underlie innovation, and are indispensable for mastering new technologies, and adapting them to local conditions. While in industrialized economies the adopters and users of technology typically already possess particular kinds of knowledge and skills required to innovate, in developing countries these capabilities need to be developed for operating new processes or for producing new products. Second, this study relates to the R&D spillovers'[52] literature, albeit limited spatial knowledge spillovers (Audretsch and Feldman, 1996) that mutually influence firms' innovative performance within a limited space. These interactions among firms depend on their level of R&D and technological capabilities, on the importance of technology transfer, and on their networking intensity.

We focus on the innovative outputs, new products, and new processes, recognizing that they are the consequence of a more fundamental transformation that occurs within an innovating firm (Geroski et al. 1993). In addition, the differences between product and process innovation are considered, keeping in mind that usually Brazilian firms are more prone to introduce process innovation than product innovation[53]. Even if new products or processes strengthens a firm's competitive position vis-à-vis its rivals[54], this distinction is important because usually different capabilities are required for each type of innovation.

Interestingly, we present an empirical framework where two waves of surveys are analysed, one before and one after the reformulation of Brazilian tax incentives[55]. We argue that even if the returns of these policies would not be seen immediately, some new trends could already become evident. This Part analyses the role of research and

[51] Freeman, 1987; Lundvall, 1992; Malerba, 1992; Nelson, 1993; Asheim and Gertler, 2005

[52] Bloom et al. (2008) develop a general framework incorporating two very important types of spillovers and implement a model using measures of a firm's position in "technology space" and "product market" space. The simplest version is to measure spillover pool as the stock of technology generated by other firms in the same industry (Bernstein and Nadiri, 1989).

[53] See De Brito Cruz and De Melo, 2006; Peirano, 2007; Goedhuys and Veugelers, 2008

[54] See Geroski *et.al*, 1993

[55] The Innovation Law in 2004 and the Fiscal Incentives Law (the so-called "*Lei do Bem*") in 2005

development (R&D) for innovation in a broad sense (without making a distinction between incremental and radical changes). We present micro estimates separately, splitting R&D from other technological capabilities (TCs), while also analyzing spillover effects.

3.2. Industrial and innovation patterns in Brazil

The Brazilian innovation gap is frequently attributed to the lack of R&D investments, both at the private and public level. One question we may ask is why this country does not invest more in R&D if high private and social returns are expected (Bloom et al., 2008)? Some explanations could be that R&D is held back by underdevelopment of financial markets or inappropriate government policies (Griffith et al., 2004). Other explanations could be that Brazilian priorities are still focused on more basic technological capabilities, such as just acquiring embodied and unembodied external technology.

Tax incentives for R&D expenditures were first introduced in 1993 by the Law 8.661/93. This law basically targeted industrial and agricultural sectors, through the "Program for Technological Development of Industry" *(PDTI - Programa de Desenvolvimento Tecnológico da Indústria*) and the "Program for Technological Development of Agriculture" (PDTA - *Programa de Desenvolvimento Tecnológico da Agricultura*), respectively, and had very low levels of participants (110 firms from 160 projects between 1994-2004)[56]. The "Innovation Law" in 2004 and the "Fiscal Incentives Law" in 2005 modified the way firms accessed the tax incentives for innovation, increasing firms' use of tax incentives for innovation, remaining still at a limited level. One positive change introduced by the latter law was to make the use of fiscal incentives for innovation much simpler and straightforward (due to elimination of the previous authorization requirements). However, in 2008 (after the revision of this law) only 522 firms, from 6000 investing in R&D, were using these incentives.

[56] See Araujo, 2008

Besides the tax incentives for R&D, and among the industrial structural conditions, Brazilian government programs[57] and policies have focused on fostering firms' industrial development in the last twenty years. State and federal[58] support initiatives to promote innovation have been designed and implemented separately, which sometimes led to overlapping institutional settings in funding and policy design. The role of the single States has been dramatically important for promoting innovation, as they enjoy full autonomy to set their own Science and Technology policies, and to have their own support agencies, higher-education centres, and research institutions.

Regarding R&D investments, only 1% of GDP, spent in public and private R&D, remain considerably low (de Brito Cruz and de Mello, 2006) compared to the EU-25 1.9% average and the US 2.6% average (Crescenzi *et al.*, 2007). Furthermore, in Brazil about 60% of R&D activity is carried out and financed by the government, and almost two-thirds of this government spending is directed to public universities and research institutions, with a small share directed to business (de Brito Cruz and de Mello, 2006).

Concerning private R&D and fixed capital (total and mean) investments, we observe in Appendix .1., the fluctuating trend during the last years that indicates a decrease from 2001 to 2003 and a recovery from 2003 to 2005. Fixed investments as a proportion of sales represent the only increasing trend, even though the number of firms investing in fixed assets has decreased, as a proportion of all firms, since 2001. Nevertheless, there is a constant tendency: the amounts invested in fixed capital are almost the 50% of what firms dedicate to R&D. The description of R&D and fixed capital investments' evolution, with particular attention to firm size, is provided in Appendix B.

Focusing on innovation outputs measures, the number of patents is still low in Brazil: the government dominates patent activity, with some academic[59] patents

[57] Some of them have been dedicated to education (Plano de Desenvolvimento da Educação – PDE); others to economic growth (Plano de Aceleração do Crescimento – PAC); and others specifically to innovation (Plano de Ação em Ciência, Tecnologia e Inovação – PACTI). "Politica de Desenvolvimento Produtivo. Innovar para sustentar o crescimento", (2008), Ministerio do Desenvolvimento, Industria e Comercio Exterior, Brazil.

[58] National Technological Development Support Program (ADTEN) is one of the instruments through which Research and Projects Financing Agency (FINEP) finances technology improvement projects for products and processes that have been executed by a company's own technical team, engineering firms, national consulting firms, universities and research institutions (De Negri et al.,)

[59] The largest holder of domestic patents is the University of Campinas, followed by the Federal University of Minas Gerais, and by the FAPESP (Fundação de Amapro à Pesquisa do Estado de São Paolo) (de Brito Cruz and de Mello, 2006)

exceptions. Brazilians were granted only 98 (or 0.06%) of the 157,497 patents issued by USPTO in 2000 (Zanotto, 2002). Concerning the number of scientific publications, they have been growing over time since 1981, and in particular over the last ten years, in the relative number of articles by Brazilian authors (Zanotto, 2002). Nevertheless, the gap in human resources widens as the country faces a shortage of higher-education graduates, especially in engineering and science (de Brito Cruz and de Mello, 2006).

Brazil's overall innovation rate is lower than the European average of about one-half (de Brito Cruz and de Mello, 2006). Only 11% of innovative enterprises in Brazil cooperate with other firms, universities or research institutions, compared to 17% in the European Union (Cassiolato *et al.*, 2005). Brazilian firms rely more on clients and suppliers as a source of knowledge than their European counterparts (de Brito Cruz and de Mello, 2006).

As previously anticipated and shown in Appendix A.2., there is a constant pattern about process and product innovation in Brazil over the years: firms tend to engage more in process rather than in product innovation.

3.3. Theoretical framework

We may wonder what Brazilian firms lack to become more innovative. Innovation requires a "supporting structure" (Baldwin and Johnson, 1996) consisting of capabilities such as education, skills, organization, management, financial, etc., to acquire and accumulate knowledge and to build the capacities indispensable for generating this change (Bell and Pavitt, 1993; Baldwin and Johnson, 1996). We focus then on analysing how this "structure" and in particular which is the role of R&D within it.

Several studies have examined innovation, proposing along the years measures such as Solow residuals, R&D expenditure, patents, and the outcome of a firm's optimal search rule for innovation. Solow residuals relate to diffusion and are correlated with market power by construction; R&D is not reported by many firms, may be seen as an input rather than an output; patents are not always implemented as innovations and many innovations are not patented (Blundell *et. al*, 1995); and the search process is assumed to generate innovation in future periods, maximizing its current information set. Only the latter methodology allows unraveling the importance of the incentive to innovate (Blundell *et al.*, 1999).

In this Part we aim to shed some light on the determinants of current innovation in terms of past values of observable firm's specific capabilities and we propose the following stylised innovation equation:

$$I_{it}=f_{it}\ (TCs_{it},\ R\&D_{it}, X_{it}, U_{it})\text{for } i = 1,\ldots\ldots, \text{N and } t = 1, 2 \qquad (1)$$

where I_{it} denotes innovation in firm *i* in time *t*, f_{it} varies across firms and time. We split[60] technological capabilities into $TCs_{it,}$ which reflect firm *i* technological capabilities (TCs) at time *t-1*, and $R\&D_{it}$ (a crucial TCs) which represent firm's *i* research and development (R&D) stock investments during time *t* and *t-1*. X_{it} is the vector of firm *i* characteristics (size, age, sector) and U_{it} is related to the unobservable[61] properties (to the econometrician) such as firm's financial structure, organization, management, etc.

Following different capabilities theories[62] devoted to study how firms keep on their technological paths (see Appendix C), we specify $TCs_{it,}$ through firms' technological competencies and targeted investments (fixed capital expenditures, skills, training, quality, external knowledge, and organization changes), grouping them into investment, production, linkages (Lall, 1992) and strategic capabilities[63]:

$$TCs_{it}=f_{it}\ (InvTCS_{it},\ PrTCs_{it}, LkTCs_{it},\ StrTCs_{it})\ \text{for } i = 1,\ldots, \text{N and } t = 1,2 \qquad (2)$$

[60] We make a substantive assumption about the separability between R&D and the other technological capabilities in order to highlight the impact of R&D stock.

[61] Other properties, like the different appropriability conditions of research efforts and the technological opportunities facing firms, are almost impossible to measure (Blundell et.al, 1995)

[62] TCs have been particularly used when analyzing developing countries (Pack and Westphal, 1986; Dahlman *et.al*, 1987; Katz, 1997; Lall, 1992; Bell and Pavitt; 1993, Romijn, 1997; Pietrobelli, 1998; Wignaraja, 1998, 2002 and 2008; Figueiredo, 2002, 2005 and 2008, Iammarino *et al*., 2008), in particular to explain the role of foreign technology in contributing to build up a stock of proprietary technology and firm specific know-how (Katz, 1984). In emerging countries the starting point in technological development is frequently this: firms need competences for improving or adapting technology to local conditions.

[63] We introduce a new category to the traditional Lall's taxonomy (1992) in this Part, underpinning the importance of firms' changes in corporative, organizational and environmental strategic decisions. We call them *Strategic Capabilities.*

where f_{it} varies across firms and time, $InvTCS_{it}$ denotes firm's *i* investments projects capabilities at time *t*, $PrTCs_{it}$ reflects firm's *i* production capabilities at time *t*, $LkTCs_{it}$ represents firm's *i* linkages capabilities at time *t*, and $StrTCs_{it}$ means firm's *i* strategic capabilities at time *t*.

Even if there is not a strict "sequence of learning", as different firms adopt different technologies learning paths depending on the nature and sophistication of their required technological knowledge, it seems that technology mastery would proceed from simpler to more difficult activities (Lall, 1992). However, it is expected that firms require a set of "core capabilities in R&D" (Nelson, 1991) to generate innovation and to assimilate and exploit knowledge from the environment (Cohen and Levinthal, 1989). Furthermore R&D is recognized to be one of the most important determinants of innovation (Acs and Audretsch, 1988; Cohen and Levinthal, 1990; Love and Roper, 1999, 2001; Freel, 2000; Hagedoorn and Cloodt, 2003; Love and Mansury, 2007).

Within developing countries, and due to frequent low levels of technology sophistication, industrial production is supposed to rely frequently on simple skills and activities, on acquiring stable and mature technology from industrialized countries, and through the accumulation of production experience ("learning by doing"). Even in these cases, developing TCs require constant efforts in investing and improving techniques, and not only passive "learning by doing": if limited to basic levels, capabilities only allow minor incremental changes that can be achieved (Bell and Pavitt, 1993).

The distinction between creating and operating industrial TCs is often hard as both of them are often closely linked. Splitting R&D from TCs, our challenge is to identify its importance in Brazil[64] as a source of innovation in a broad sense (without making distinction between innovation and imitation) (Cohen and Levinthal, 1989; Aghion and Howitt, 1997; Howitt, 2000; Griffith *et al*., 2004).

There is a wide theoretical literature[65] that suggests that R&D activity plays an important role in technology transfer (Griffith et al., 2004). The rate of return of

[64] Bell and Pavitt (1993) argued that in science based industries technology is accumulated only by R&D laboratories. We argue that due to the speed of technological change, we expect R&D to be crucial in every type of industry.

[65] Bloom *et al.* (2008) construct a pool of product-market R&D, to measure spillovers within the same technology class, but rules out spillovers between different classes. They also develop a new distance measure which exploits the Mahalanobis norm to identify the distance between different technology classes based on the frequency that patents are taken out in different classes by the same firm.

spillover is to be a function of different factors such as technology knowledge and product market rivalry (Bloom *et al.*, 2008) and also the spatial distance between firms. Focusing on the latter aspect, on the one hand, localized R&D facilitates the collective learning process that characterizes innovation (Cooke and Morgan, 1994; Audretsch and Feldman, 1996). On the other hand, knowledge externalities[66] of R&D diminish by geographic and technological distance (Adams and Jaffe, 1996) such as tacit knowledge, difficulties of knowledge transmission, etc., generating evidences of weak locational innovation effects (Jaffe, 1989; Jaffe *et al.*, 1993; Feldman, 1994; Meyer-Stamer, 1998; Love and Roper, 1999).

As reflected in our basic innovation equation (1.), knowledge adoption requires effective efforts and absorptive capacity (R&D) by the receiving firms. There is ample evidence that also, to realize the benefits from spillovers from other firms' R&D activities the incumbent firm has to engage in technological efforts, such as investing in R&D (Kamien and Zang, 2000). Given the relationship between innovation and the studied variables, we aim to include the impact of geographic spillovers. Thus, our new extended innovation equation takes the following form:

$$I_{it}=f_{it}\ (TCs_{it},\ R\&D_{it},\ X_{it},\ CumR\&D_{it},\ U_{it})\ \text{for}\ i = 1,\ldots\ldots,\ \text{N and}\ t = 1, 2 \qquad (3)$$

introducing $CumR\&D_{it}$ as our measure of spillovers that analyses the influence of "extramural knowledge" (Cohen and Levinthal, 1989) over firms innovative performance, considering neighbors' R&D investments. The underpinning intuition is that a firm's *i R&D* efforts contribute to its ability to benefit from other firms' spillovers. If spillovers are relevant for a firm's *i* innovative performance, it constitutes a positive signal about firms' current R&D stock, albeit, sometimes a disincentive to invest in more R&D that can provide spillovers to rivals[67] (Cohen and Levinthal, 1989, 1990; Kamien and Zang, 2000).

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[66] Firms can learn horizontally, from spillovers with origin in other producers and competitors, or vertically, by interacting with upstream suppliers and downstream users, as well as from independent research carried out in the regional, national or international science and technology system by universities and research institutes (Iammarino *et al.*, 2009)

[67] The speed in which R&D leak out can be another influential factor though not analysed in the present Part (see Mansfield, 1985)

3.4. Econometric specification

According to the theoretical model the following econometric equation can be estimated, where the subindexes *i* and *t* refer to individual firm and time respectively, and subindex *k* refers to Unit of Federation (UFe):

$$P(y_{it} = 1 \mid TCs_{it}, R\&D_{it}, X_{it}, CumR\&D_{kt}\ U_{it}) = E(y_{it} \mid TCs_{it}, R\&D_{it}, X_{it}, CumR\&D_{kt}\ U_{it}) = \beta_1 TCs_{it} + \beta_2 R\&D_{it} + \beta_3 X_{it} + \beta_4 CumR\&D_{kt} + \beta_5 U_{it} \quad (4)$$

$i = 0, \ldots\ldots\ldots, N$

$t = 1,2$ year of the survey (2003 and 2005)

$k = 0, \ldots\ldots, 27$

where y_{it} is the innovative output of the firm, TCs_{it} are firms' Technological Capabilities, $R\&D_{it}$ is the internal and external expenditure in R&D, and X_{it} are the other firms' characteristics (size, age, foreign ownership) and controls (year, sector, UFe), $CumR\&D_{kt}$ is the sum of firms' investments in R&D within the same UFe, and U_{it} are the unobservables that are an important feature of any empirical model of innovation activity (Blundell et.al, 1995).

The observable binary dependent variable takes value one if firms introduce a new product for the Brazilian market, a new process for the sector in Brazil, or either of them, and zero otherwise. As stated previously, we consider separately innovations associated with the introduction of new products and new processes. Product innovators are the ones who introduced at least one new product to the Brazilian market over a three year period – including the year of the survey. The same occurs for processes innovators, but regarding the introduction or improvement of at least one new process, to their sector within Brazil.

The binary character of the dependent variable leads us to formulate the model in terms of a latent variable y^* that is linearly related to the explanatory variables (Bertschek and Lerner, 1998), and that can not be observed. What we observe is only the realization of innovation (Harris *et.al*, 2003):

$$Y_{it} = 1\ (Y^* > 0) \quad i = 0, \ldots\ldots\ldots, n \text{ and } t = 1, 2 \qquad (5)$$

where the indication function 4 (.) equals one if the expression in brackets is true and zero otherwise.

3.4.1. Technological Capabilities: the Technology Index

We select to work with the Capability Score or Technology Index (Gonsen, 1998; Lall and Latsch, 1999; Wignaraja, 2002 and 2008) based on the Lall's taxonomy (2002). Each firm is evaluated over the four types of capabilities[68] (see Appendix E.2.). Technical activities are grouped according to this classification, and their importance has to be assessed by the firms on a four-point scale, depending on the importance they assign these functions in the past three years. We are interested in the overall score of capabilities (TCs) which includes different technical functions except R&D.

The enterprise with the highest grades would have a maximum of 40 points, obtained as the sum of the maximum grade in each function. For better comparison between enterprises, the original grading is divided by the maximum grade (40), thereby assigning the same relative importance to each of the twelve functions.[69] This new value that ranges between 0 and 1, is then a summary score of TCs for each firm.

3.4.2. R&D Stock

As previously argued, R&D remains one of our crucial determinants of innovation. It is usually considered to be the leading dynamic capability of a firm (Nelson, 1991) and due to its extreme importance we treat it separately from the other TCs. Following the logic of innovation path-dependence, we estimate R&D considering that the present innovation is also due to past R&D investments. Hence we assume that the firm's "R&D stock" depends on the current (*t*) and past (*t-1*) flows of R&D and a depreciation rate (Blundell *et al.*, 1999):

$$R\&D_{it} = R\&D_{it} + (1 - \delta)\, R\&D_{i(t-1)} \qquad (5)$$

[68] This is a modified version of Lall's taxonomy (1992). The original one includes only three categories.

[69] As stated by Westphal et al. (1990 pp.87), "the Capability Scores are biased estimates with respect to the measurement of capabilities cum capacities per se. The degree of bias depends on the respective weights placed on capability and sophistication in the researchers' scoring. Unfortunately, it is not possible to state these weights…" The overall Capability Score is often referred as a Technology Index or TI (Wignaraja, 2008).

where δ is a depreciation rate. The underlying intuition is also that knowledge[70] – or in particular R&D- depreciates because other firms can imitate innovation. Furthermore, using R&D lagged two periods may contribute to eliminate endogeneity biases (Griffith *et al*., 2004).

3.4.3. CumR&D (Spillovers)

We create a measure of spillovers[71] by adding up contemporaneous R&D expenditures in neighboring firms within the same UFe. The scope is to check if R&D investments exert any influence over neighbor firms' innovative behavior. Total effective density of R&D should be more accessible to any firm located in the same UFe and generate spillover effects within it and should contribute as a knowledge source external to the firm (Kline and Rosemberg, 1986). And it should be related to the levels of firms' TCs, and in particular R&D, which influence firms' ability to absorb external knowledge and to innovate (Cohen and Levinthal, 1989; Lopez, 2008).

3.4.4. Firms' characteristics and controls

Firms' size, age, and foreign ownership variables are also included in the model. Firms' size is then highly contrasted in literature as having a dual or inconclusive effect on firm innovative behavior (Acs and Audretsch, 1988; Shan et al. 1994; Arvanitis and Hollenstein, 1996; Grupp and Maital, 2000; Meeus and Oerlemans, 2000; Galende and de la Fuente, 2003) and as being unrelated to the economic value of innovation (Tether, 1998). In some studies the probability of investing in R&D is expected to increase with firm size (Schumpeter, 1942; Horowitz, 1962; Lall, 1983; Henderson and Cockburn, 1996; Cohen and Klepper, 1996; Arvanitis, 1997; Crepon *et al.*, 1998, Swamidass and Kotha, 1998; Swamidass, 2003). Nevertheless, other studies highlight that that large firms do not conduct a disproportionate amount of

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[70] This logic can be extended to personnel moves and machine wear out (Blundell et al., 1999)

[71] Various strategies have been employed to assess the relevance of R&D spillovers and to measure the inherent limitations of the R&D data to identify the effects of geographical and technological distance. Apart from the difficulties only due to measuring spillovers, there are some problems related to R&D measurement. For instance Griliches (2000) highlights the simultaneity problem. It is referred to the possible confusion in causality: future output depends on past R&D, while R&D in turn depends on past output and expectations for the future.

R&D relative to their size. They undertake R&D investments only up to a threshold level (Kumar and Saquib, 1996) and generate fewer innovations per dollar of R & D than smaller firms (Tether, 1998). Indeed, other evidence shows that small firms achieve more innovations than their larger counterparts, underscoring that small firms are more innovative as well as more efficient innovators (Schumacher, 1973; Kleinknecht *et al*., 1993; Cohen, 1995; Love and Roper, 1999). Finally, size advantages and disadvantages may strongly depend on sectors (Pavitt *et al*., 1987; Rothwell and Dodgson, 1994).

Firms' age reflects learning and experience (Kumar and Saquib, 1996; Kuemmerle, 1998; Galende; De la Fuente, 2003) and it is supposed to have a positive effect on innovation. However there are exceptions: sometimes new firms are more prone to spur creativity than established firms, as they are created with the scope of introducing new products to the market (Bollinger et al., 1983; Molero and Buesa, 1996).

Foreign ownership is frequently expected to contribute to firms' innovation as it allows them to have access to external sources of knowledge, technology and markets (Mansfield and Romeo, 1980; Westphal *et al.*, 1990). Frequently, foreign-owned firms are more likely than their local counterparts to innovate (Love and Roper, 2001). In particular, in developing countries its importance depends on the type of relationships that firms have with their foreign owners, on their sharing of knowledge, and on the quality of intellectual property rights in the host country (Almeida and Fernandes, 2007).

The sector (CNAE) to which a firm belongs represents another important analytical level of understanding, and it is also included as a control in the model. There are specific patterns in a given sector called by Breschi et al. (2000), "technological regime". It consists in specific values of technological opportunities, appropriability of innovations, cumulativeness of technical advances, and properties of knowledge base[72] (specific knowledge) and is intrinsically related to innovation. However, these sector patterns may also vary across firms' locations (Cohen, 1995; Meyer-Stamer, 1998; Love and Roper 2001).

The effect of spatial autocorrelation (i.e., the lack of independence among the error terms of neighboring observations) is minimized by including a set of UFe dummy

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variables accounting for the pertinent fixed effect (Crescenzi *et al*., 2007). Brazil exerts a context of heterogeneity across regions and sectors (Haddad and Hewings, 1999) and only neighbor firms may be facing similar conditions and consequently exerting regional or even local behaviors.

3.5. Results of the analysis

3.5.1. Estimation issues and data availability

In the first step we verify how the chosen regressors impact on the probability of introducing new products, new process or either of them, by running a Probit model. We select firms as our units of observation. We study two datasets to capture all unobserved characteristics that are firm specific and time invariant components. The advantage is the fact that Pintec 2005 followed firms already evaluated with Pintec 2003. Nevertheless, there are still some challenges related to the idiosyncratic component of the error term that may represent stochastic shocks of technology (Parisi *et al.*, 2006), differences in firms' management, increasing competition, etc.

Our data sources are the Brazilian Innovation Surveys Pintec 2003 and 2005, conducted by the IBGE (Instituto Brasileiro de Geografia e Estatistica) according to the Oslo Manual 3rd Edition and the Community Innovation Survey (CIS III). The former survey includes 10.000 firms. It refers to firms' previous year information, while only for the qualitative variables, it covers the past three years. Under the same assumptions, the latter survey was carried out considering 12.000 industrial firms and following up most of the enterprises of the previous survey.

Pintec information refers to firms registered in the CNJP (Cadastro Nacional de Pessoa Juridica) classified by the CEMPRE (Cadastro Central de Empresas-IBGE) as industrial ones, with more than 10 employees. These firms are then included in section C and D (extractive and transformation industries) of the CNAE (Classifição Nacional de Atividades Economicas) and are classified according to three digits CNAE.

Our first caveat refers to stratification. Without the possibility of screening all the firms included in CEMPRE, the sample has been constructed using almost only innovative firms. As Pintec considers innovation as a rare phenomenon, if it follows the traditional design sample model -consisting in random stratification (by firm size, location, and activity) of firms- only a few innovative firms would be included. In spite of this, Pintec includes firms that have more probability of innovating. They are identified using two groups of indicators (principal and secondary) built on other sources of information such as Patents and Technology Transfer Contracts database from the Cadastro do Ministério da Ciência e Tecnologia (MTC); Pia (Pesquisa Industrial Annual), including specific firms that invested in new equipment, in royalties, in technical assistance, among others; FDI census from Banco Central, etc. Pintec, then, proceeds with a three levels stratification process, based on the probability of being an innovator -according to these two groups of indicators. The "certain" stratus includes large firms (with more than 500 employees) with at least one principal indicator of technological activities. On the other extreme, firms without any indicator of technological activities are considered as not eligible. The sample is finally constructed with the 80% of eligible firms and the 20% of non eligible firms. The second level of stratification allows obtaining reasonable regional estimates in both UFe and Large Regions and also regarding economic activities.

The second caveat refers to the fact that the surveys' information is restricted to two types of firms: one includes firms that have at least incomplete projects of products or processes innovation, and the other regards firms that introduce new products or new processes. If firms give a negative answer to both questions, they are only asked to give information about obstacles for innovating without providing any other data about R&D investments, Quality Certification, skilled employees, training, etc. We focus then only in firms that innovate in product or in process.

3.5.2. Results

The results for our function 4 (.) for *t*= 2003 and *t*=2005, with the three alternative dependent variables, product innovation (Columns 1 and 4), process innovation (Column 2 and 5) and innovation (Columns 3 and 6) are presented in Tables 15. Appendixes D1 and D2 provide the variables description. In all the estimations 1-6 of Tables 16, we control for spillovers' effect by introducing the variable relative firms' R&D expenditure within the same UFe. All the specifications control for geographic UFe and for the three digits CNAE sectors.

Table 15 – Probit estimations of the empirical model – Cross Sections 2003 and 2005

	PINTEC 2003			PINTEC 2005		
	Product Innovation	Process Innovation	Innovation	Product Innovation	Process Innovation	Innovation
R&D Stock	0.0449***	0.0367***	0.0419***	0.0826***	0.0537***	0.0774***
TCs	2.8879***	3.2956***	3.2040***	2.6644***	2.9602***	3.0612***
R&D Cum	0.3377***	0.0008	0.01138	0.0309	0.5927***	0.0569
Size	0.0002***	0.0001***	0.0002***	0.00008***	0.0001***	0.0001***
Age	0.0024	0.0056**	0.0039**	0.0017	0.0019	0.0016
Fe	0.2986***	0.4212***	0.4069***	0.3708***	0.3937***	0.4420***
Pseudo R-Squared	0.3323	0.3729	0.3576	0.3168	0.3176	0.3394
Log pseudolikelihood	-1692.3394	-1142.4399	-1942.9089	-2335.4985	-1579.7423	-2665.286
Sector dummies	X	X	X	X	X	X
Geographical dummies (Ufe)	X	X	X	X	X	X
Number of observations	10270	10270	10270	12062	12062	12062

Notes: R&D is the sum of external and internal expenditure in R&D. * Significant at 10%, ** significant at 5%*** significant at 1

The set of coefficients is statistically significant in terms of Chi-Squared distribution at less than 1%. The McFadden's[73] pseudo R² confirm the overall goodness-of-fit of all the estimations presented. Iteraction log shows fast convergence of the model (in most of the cases in only 18 or 19 iteractions). In all cases we present standard errors that are robust to heteroskedasticity.

We uncover a number of insights into the relationship between TCs, R&D, and innovation. TCs are positively and significantly related to the probability of introducing new products, new processes or "either" innovation in both surveys. As we keep R&D separate from the other TCs, we obtain some interesting findings: R&D stocks are positively and significantly related to the probability of innovating in the three studied cases; however, R&D spillovers seem not significant regarding the introduction of new process and just innovation in 2003, and new process and "either" innovation in 2005. One explanation may be that Brazilian manufacturing firms are not able to fully benefit from spillovers, in not having the required absorptive capacity (Cohen and Levinthal, 1990), mostly related to R&D. The other explanation can be related to the use of a "cross section" model, which neglects firms' heterogeneity leading to biased estimators and wrong inferences (Tiri, 2007).

Regarding the control variables, the probability of introducing new products is found to increase specially within foreign-owned large firms. As the nature of the survey question may not reflect innovation intensity, larger firms may be over

[73] For a comparison between different popular pseudo R² measures see Hoetker (2007, p.340)

represented even though intensity of innovation is similar. However, the relationship between firms' size and innovation is also in line with the idea of economies of scale in innovative activity (Harris et al., 2003). Conversely, firms' age exerts scarce influence on the probability to innovate (only significantly and positively related to the probability of introducing new process or just innovating in 2003) in Brazilian manufacturing firm.

In order to address some of the possible bias and wrong inferences, we explore the panel structure provided by the two surveys used jointly of the data. Considering a short period of time, we expect it to hold exogeneity as no important mechanisms of feedback would be verified (Blundell et al., 1995). In Table 16, we pooled the database and work with a short-panel (two years), under the assumption that standard errors are independent across the individuals (Cameron and Trivedi, 2009), obtaining cluster-robust errors. In all the estimations 1-6 of Table 16, we control for spillovers effect by introducing the variable relative firms' R&D expenditure within the same UFe. All the specifications control for geographic UFe and for the three digit CNAE sectors, and for years.

Table 16 – Probit estimations of the empirical model – Panel Probit (RE) and Logit (RE)

	Probit Random Effect			Logit Random Effects		
	Product Innovation	Process Innovation	Innovation	Product Innovation	Process Innovation	Innovation
R&D Stock	0.0743***	0.0529***	0.0697***	0.1334***	0.0968***	0.1241***
TCs	3.6528***	3.8225***	4.0719***	6.9933***	7.6004***	7.7321***
R&D Cum	0.0580***	0.0570***	0.0471***	0.1151***	0.1245***	0.0963***
Size	0.0001***	0.0002***	0.0002***	0.0003***	0.0003***	0.0004***
Age	0.0031***	0.0042***	0.0035***	0.0065***	0.0091***	0.0070***
Fe	0.4822***	0.5052***	0.5662***	0.9008***	0.9634***	1.0548***
Wald Chi (37)	923.28	687.95	1080.71	976.34	792.83	1105.97
Log likelihood	-3995.3222	-2730.4798	-4576.8685	-4009.3865	-2744.2931	-4591.7406
Prob > Chi2	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Sector dummies	X	X	X	X	X	X
Geographical dummies (Ufe)	X	X	X	X	X	X
Number of observations	22907	22907	22907	22907	22907	22907

Notes: R&D is the sum of external and internal expenditure in R&D. * Significant at 10%, ** significant at 5%, *** significant at 1%

We test two alternative methods allowing for two different distributions. There are practical reasons for favoring one or the other methodologies (in some cases it may be mathematical convenience), but it is difficult to justify the choice of one distribution or another on theoretical grounds (Greene, 2002). The first column reports the Panel

Probit model fitting via Maximum Likelihood random effects model, imposing normal distribution. The subsequent columns report the results from Random Effects Panel Logit model fitting also random effects, imposing logistic distribution on the data. Our results show that the two procedures yield similar parameter estimates and, as expected, the coefficients[74] from the Panel Logit estimators are higher than the standard Probit model. The Wald (Chi) statistics indicates that the sum of the coefficients do not equal one; hence, the results are robust to heteroskedasticity.

The upshot of these results is that TCs, R&D, and R&D spillovers complementary increase probability to introduce new products to the market, new process to the sector, or either type of innovation. Our baseline specification made in Equation (1.) assumes that TCs and R&D are the critical factors in generating innovation; nevertheless, we prove the importance of including also R&D spillovers (Equation 4.) which play a fundamental role for increasing the probability to innovate. Indeed, the existence of such positive externalities suggests the acknowledgment of the required absorptive capacity that facilitates the rate of innovation. These results are robust to our selected controls (sector and UFE differences).

Confirming the results of the cross section models, we found that size and foreign ownership are positively and significantly related to the probability of introducing new products to the market, new process to the sector, or either type of innovation. Despite the cross section results, the panel model allows including age as a relevant characteristic for being an innovator.

3.6. Concluding remarks

In this Part we explored the highly diversified theoretical and empirical evolution in the relationship between R&D, innovation, and other technological capabilities. Different visions and methodologies allowed us to depart from the linear model of innovation that concentrates on the R&D, focusing on a deeper understanding of the nature and dynamics of innovation, which involves including in the debate the complementary role of other technological capabilities.

[74] "Since the logistic density descends more slowly than the normal, for unbalanced samples such as ours, the ratio of the logit coefficients to the probit coefficients will tend to be larger than 1.6" (Greene, 2002, p.676).

We analyzed the role of R&D for building absorptive capacity within firms. For this purpose, we introduced different theoretical visions that claim that are R&D expenditures are dramatically important for innovation revealing that in many cases, they are not sufficient to its achievement. Other technological capabilities, in particular within emerging countries, are required to keep the paths of technological change.

We focused on Brazilian manufacturing firms and discussed the main patterns of industrial activity that foster innovation. One interesting point has been emerging as a constant over the years: Brazilian firms are more prone to introduce processes innovations rather than products innovations, maybe in some way due to the scarcity of R&D public and private investments so closely related to product innovation. Indeed, the scant 1% of GDP Brazilian public expenditures in R&D is accentuated by the fact that most of the Brazilian spending is directed to universities and research centers rather than to business firms. The Federal States also play a crucial role in promoting innovation, but uncoordinated policies with the central government sometimes results in overlapping and waste of resources.

Several alternatives of measuring innovation and technological capabilities (TCs) have been proposed by the literature and have been evaluated in this Part. Regarding the former, we opted to analyze innovation as an output, measured by the creation of new production processes for the sector, new products for the market, or either of them, for this study. Concerning the latter, we constructed an overall technology index as proxies of TCs.

Using firm-level data from Pintec 2003 and 2005 for cross section analysis of Brazilian manufacturing firms, the results did not provide evidence of different drivers for product and process innovation, suggesting that our two key variables of interest TCs and R&D stock, lie behind both type of innovation.

We produced econometric evidence of the double role of R&D investments in emerging countries: one was that R&D stocks increase firms' absorptive capacity, complementing the process of building TCs (crucial for emerging countries) and allowing firms to innovate. The other was that R&D stocks stimulate the probability to innovate among neighbour frms. An implication of these results is the importance of continuity in R&D investments as they are path-dependent and are not limited to the introduction of innovation, but belong to the more complex process of building TCs.

We confirmed firm heterogeneity, age, size, and foreign ownership are relevant characteristics for increasing the probability to innovate in a broad sense. Our findings are robust for the control of several firms' characteristics, such as geographic location and sector.

In addition, after controlling for some of the possible bias and wrong inferences through the panel estimates, positive externalities arose. They were R&D knowledge spillovers, which meant that firms R&D investments in the same UFE increased neighbor firms' probability to innovate. Future research should investigate if market conditions may foster or hamper firms' decisions to continue investing in R&D, considering the existence of spillovers and the importance given to the private return of R&D investment. Hence, if firms in some sectors are less interested in investing in R&D, the State would emerge as the crucial actor for sustaining innovation through public R&D investments.

Appendix D. 1.R&D and fixed investments

	2001	2003	2005
Total investments in R&D	R$ 22,343,759	R$ 18,491,296	R$ 24,366,841
Number of firms (R&D > 0)	19 165	20 599	19 951
Mean of R&D investment	R$ 1,165.84	R$ 897.66	R$ 1,221.33
Total investments in Fixed Investments	R$ 11,667,339	R$ 9,182,629	R$ 11,788,646
Number of firms (Fixed investment > 0)	15 540	16 250	15 680
Mean of Fixed investment	R$ 750.79	R$ 565.09	R$ 751.83
R&D / Total investment	65.70%	66.82%	67.39%
R&D investment/Sales	3.84%	2.46%	3.92%
Fixed investment/Sales	2.00%	3.44%	6.56%
Share of firms (% of total firms)			
R&D investment	26.62%	24.45%	21.91%
Fixed investment	21.58%	19.28%	17.22%

Source: IBGE, Pintec (Pesquisa de Inovação Tecnólogica) 2001, 2003 and 2005
Notes: number of firms counts all firms with R&D or fixed investments greater than zero. All variables expressed in R$ (1000) are deflated with the appropriate Consumption Price Index **(**Índice Nacional de Preços ao Consumidor Amplo, IPCA - IBGE), base 2001.

Appendix D. 2.Product and Process Innovation

	2001	2003	2005
Number of sampled firms	72 005	84 262	91 055
Number of firms - Product Innovation	12 658	17 146	17 784
Share of firms with Product Innovation	17.58%	20.35%	19.53%
Number of firms - Process Innovation	18 160	22 658	24 504
Share of firms with Process Innovation	25.22%	26.89%	26.91%
Number of firms - Product, Process or either Innovation	22 698	28 036	30 377
Share of firms with Product, Process or either Innovation	31.52%	33.27%	33.36%

Source: IBGE, Pintec (Pesquisa de Inovação Tecnólogica) 2001, 2003 and 2005

Appendix E. R&D and fixed investments (by size)

Number of employees	10-29	30-49	50- 99	100-249	250-499	More than 500
Number of firms (R&D) 2001	9 937	2 618	2 765	1 928	922	995
Number of firms (R&D) 2003	11 916	3 051	2 413	1 656	650	912
Number of firms (R&D) 2005	10 691	2 420	2 685	2 204	934	1 016
Mean of R&D investments 2001	R$ 144.21	R$ 178.80	R$ 474.44	R$ 1,436.11	R$ 2,601.41	R$ 14,028.93
Mean of R&D investments 2003	R$ 89.29	R$ 142.30	R$ 455.32	R$ 956.81	R$ 2,333.47	R$ 14,023.24
Mean of R&D investments 2005	R$ 147.15	R$ 579.56	R$ 432.45	R$ 734.09	R$ 2,633.78	R$ 12,789.47
Number of firms (Fixed Invest) 2001	8 251	2 062	2 061	1 527	738	901
Number of firms (Fixed Invest) 2003	9 290	2 369	1 934	1 369	505	783
Number of firms (Fixed Invest) 2005	8 484	1 748	2 080	1 745	772	851
Mean of Fixed investments 2001	R$ 134.97	R$ 145.92	R$ 431.94	R$ 1,297.21	R$ 1,844.92	R$ 6,682.06
Mean of Fixed investments 2003	R$ 75.47	R$ 102.63	R$ 402.46	R$ 681.14	R$ 1,819.29	R$ 7,167.30
Mean of Fixed investments 2005	R$ 132.62	R$ 418.96	R$ 388.61	R$ 510.83	R$ 2,135.92	R$ 5,940.28
R&D / Total capital investment 2001	56.27%	60.87%	59.58%	58.29%	63.79%	69.88%
R&D / Total capital investment 2003	60.28%	64.10%	58.53%	62.96%	62.28%	69.52%
R&D / Total capital investment 2005	58.30%	65.70%	58.96%	64.48%	59.87%	71.99%
Share of R&D firms 2001	21.11%	27.47%	36.59%	41.44%	50.59%	73.16%
Share of R&D firms 2003	21.62%	25.35%	26.35%	33.94%	38.36%	66.90%
Share of R&D firms 2005	18.02%	18.67%	26.75%	41.29%	50.69%	66.12%
Share of FI firms 2001	17.52%	21.64%	27.27%	32.83%	40.49%	66.21%
Share of FI firms 2003	16.85%	19.68%	21.12%	28.04%	29.80%	57.39%
Share of FI firms 2005	14.30%	13.49%	20.72%	32.69%	41.90%	55.37%
R&D investment/Sales 2001	5.06%	2.59%	3.97%	4.27%	3.27%	3.83%
R&D investment/Sales 2003	3.44%	0.01%	2.53%	1.91%	1.79%	2.62%
R&D investment/Sales 2005	4.65%	6.48%	2.85%	2.13%	3.05%	2.54%
Fixed investments/Sales 2001	3.94%	1.67%	2.69%	3.06%	1.86%	1.65%
Fixed investments/Sales 2003	2.27%	1.08%	1.80%	1.12%	1.09%	1.15%
Fixed investments/Sales 2005	3.32%	3.38%	1.98%	1.17%	2.05%	0.99%

Notes: number of firms counts all firms with R&D or fixed investments greater than zero. All variables expressed in R$ are deflated with the appropriate Consumption Price Index (Índice Nacional de Preços ao Consumidor Amplo, IPCA - IBGE).

Appendix F . Different indicators of Capabilities in developing and developed countries

Developed Countries	Indicators of capabilities	Approach	Location
Cohen and Levinthal (1990)	R&D intensity and spillovers	AC	US manufacturing sector
Helfat (1997)	R&D expenditures and applications	DC	US energy firms
Brown and Eisenhardt (1997)	Multiple product development processes	DC	Computer industry
Deeds (2001)	Number of patent applications, number of products in pre-clinical trials, number of products in clinical trials, and number of products on the market	RBV	US pharmaceutical biotechnology firms
Verona and Ravasi (2003)	Qualitative measure of knowledge-related process and capabilities	DC/RBV	Danish hearing-aid industry
Griffith, Redding and Van Reenen (2003)	R&D induced innovation, technology transfer, and R&D-based AC	AC	US manufacturing sector
Dutta et al. (2005)	Stochastic frontier estimation (SFE) to infer capabilities based on R&D expenditures and environmental conditions	RBV	Semiconductor and computer equipment industries in US
Coombs and Bierly (2006)	Patent statistics and a measure of R&D intensity as indicators of TCs	KBV	US public manufacturing companies
Developing Countries	**Indicators of capabilities**	**Approach**	**Location**
Katz (1984)	Sequential process of acquiring TCs	TCs	Manufacturing firms in six Latin American countries
Westphal *et al.*(1990)	Technology Index testing firms' size, ownership, and market orientation	TCs	Electronics, biotechnology, and materials technology firms in Thailand
Amsden and Mourshed (1997)	R&D, patents, and scientific publications	TCs[75]	Compare firms in OECD and late-comers countries
Figueiredo (2002)	Paths of inter-firms differences in TCs	TCs	Steel firms in Brazil
Romijn (1997)	Quantitative measures of learning mechanisms	TCs	Capital goods firms in Pakistan
Wignaraja (2002)	Technology Index and econometrical analysis of factors affecting TCs	TCs	Garment firms in Mauritius
Figueiredo and Vedovello (2005)	Firms' classification of capabilities by type and by level of development	TCs	Firms in the industrial pole of Manaus-Brazil
Iammarino et al. (2008)	Process and product-centered capabilities at micro and meso levels	TCs	Electronic industry in two Mexican regions

Notes: AC (Absorptive Capacity), RBV (Resource-Based View), TCs (Technological Capabilities)

[75] The authors used a limited concept of TCs associated with "technological skills"

Appendix G. Innovation in Product and in Process. Different Studies.

Author	Year	Subject	Approach to innovation
Iammarino *et al.*	2008	Product and Process Technological Capabilities in FDI- dominated manufacturing firms in Mexico	Either process or product innovation
Jensen *et al.*	2007	Forms of knowledge and modes of innovation	Only product innovation
Parisi *et al.*	2006	Effects of product and process innovation on productivity in Italian manufacturing firms	Process, product, process and product, process or product
Vivarelli and Conte	2005	Determinants of innovation outputs in the Italian manufacturing sector	Product, Process and Product and Process simultaneoulsy
Mairesse and Mohnen	2005	The Importance of R&D Innovation: a Reassessment using French Data	Product and Process separated
Miravete and Pernias	2004	Complementarities between product and process innovation in the Spanish ceramic tiles industry	Product and Process separated. Also their complementarities
Loof and Heshmati	2002	Different factors that influence Swedish manufacturing firms to to innovate	Product and Process separated
Cabagnols and Le Bas	2002	Microeconomic determinants of innovative behaviour of French manufacture firms	Product, Process and Product and Process simultaneously
Sternberg and Arnt	2001	The firm or the region: What determines the innovation behavior of European Firms	Product and Process separated
Kaufmann and Todtling	2000	Systems of Innovation in Traditional Regions: the case Styria	Product and Process separated

Appendix H. Description of the variables

Table H.1. The dependent variables: definitions, notations, and values

For PINTEC 2003

Definitions of the Variables	**Notation**	**Values**
Product Innovation		
From 2001-2003, the firm introduced new products or significantly improved products for the domestic market?	Prod_Inn_03	0/1
Process Innovation		
From 2001-2003, the firm introduced new process or significantly improved process for the domestic market?	Proc_Inn_03	0/1
Product or Process Innovation		
From 2001-2003, the firm introduced new products or new process or significantly improved either of them for the domestic market?	Inn_03	0/1

For PINTEC 2005

Definitions of the Variables	**Notation**	**Values**
Product Innovation		
From 2003-2005, the firm introduced new products or significantly improved products for the domestic market?	Prod_Inn_05	0/1
Process Innovation		
From 2003-2005, the firm introduced new process or significantly improved process for the domestic market?	Proc_Inn_05	0/1
Product or Process Innovation		
From 2001-2003, the firm introduced new products or new process or significantly improved either of them for the domestic market?	Inn_03	0/1

Table H.2. The Technological Capabilities, R&D, and control variables: definitions and notations

Name of the Variables	**Notation**	**Definitions**
Investment Capabilities	TCs1	Simple mean, after adding the level of importance of projects, design, trial test, and preliminary innovative activities
Production Capabilities	TCs2	Simple mean, after adding the level of training for innovation, quality certification, and investments in new equipment
Linkages Capabilities	TCs3	Simple mean, after adding the level of importance of the external sources of information, research, and education centers and other sources of information (patents, fairs, conferences, etc.)
Strategic Capabilities	TCs4	Simple mean, after adding the level of importance of firms' corporative and organizational strategy and new production and environmental techniques
Technology Index	TCs	Simple mean, after adding TCs1, TCs2, TCs3 and TCs4
R&D Expenditures	R&D	The sum of internal and external expenditures in R&D in local currency (1000) R$
Firms' R&D expenditures (Ufe)	CumR&D	The sum of firms' R&D expenditures within the same Ufe in local currency (1000) R$
Age	Age	The difference between the surveys' year and the year in which the firm started operations
Size	Size	The number of employees at the end of the survey year
Foreign Ownership	FE	The foreign origin of the control capital (yes/no)

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4. Conclusions

This dissertation has focused on Technological Capabilities (TCs) in order to explain their relationships with exports and innovation. This set of relationships was examined under three different approaches. Part I focused on TCs and exports in Argentina, Brazil, and Chile. Part II examined firms at the centre of the food processing Sectoral Systems of Innovation, analysing how their main building blocks' patterns can increase the probability to innovate. Part III focused on Brazil and the importance of R&D and TCs for innovation. The research strategy included a descriptive quantitative approach and was based on two types of surveys: the Investment Climate Surveys (WB) and the National Innovation Surveys (IBGE, Brazil).

An overview of the industrial development process in Argentina, Brazil, and Chile has been our starting point. The intuition has been to analyse the main changes in firms' industrial behaviour, from the ISI period to trade liberalization. We found essential changes in the patterns of production after trade liberalization. Indeed, firms that were not ready to face the new reality tended to disappear, generating a new composition in each industry. However, changes meant also new opportunities for other firms, in particular in some specific sectors such as computer science, software, and other new fields. State subsidies played a fundamental role, fostering specific sectors such as the automotive sector in Argentina and the aircraft sector in Brazil. These examples constitute proof of the importance of appropriate industrial policies for developing diversified and booming industrial sectors in these countries.

Concerning the specific case of Brazil, we also briefly reviewed its innovative and industrial patterns. Many government programs and policies have been devoted to promote industrial development and innovations, both at the State and Federal levels. Nevertheless, the lack of R&D investments has been creating serious constraints to filling in the Brazilian innovation gap. Only some specific areas became outstanding examples of success (photonics, aeronautics, deep-water oil prospecting, biotechnology, etc) with few achievements in new inventions mostly due, again, to low levels of R&D spending. Another important finding, which emerged as a natural consequence, was that innovations in Brazil have been more related to processes rather than products, and that the number of patents and scientific publications has been always lower than found in either the EU or the US.

These issues gave us the framework for where we positioned our research question. The evolutionary approach gave us the means to answer it. As an extension of it, the TCs' literature underpinned the present analysis. The idea that firms are intrinsically different and need to perform indigenous efforts to keep the path of technological change has always been the basis. Among different capabilities' theories, the TCs strand of literature is considered particularly accurate to approach these arguments when examining developing countries. Two main bodies of literature address this approach, contributing to the understanding of the TCs: the TFCL and the LCL. Even if the LCL approach has been vastly applied while studying many developing countries, it provides the insight that technology has been seldom generated in-house, but generally acquired from foreign markets and adapted to local conditions. Also, the TFCL view always contributes to gaining further insight into such complex phenomenon. Indeed, the LCL is particularly interested in delving deeper into TCs accumulation while TFCL is more concerned with the underlying learning process. It should then be desirable that both approaches would be always bridged in research; in our case even if we do not explicitly give details on firms' learning process, the theoretical basis of the TFCL has been present all along in our research.

Alternative ways of measuring TCs were found in literature. The understanding of firm knowledge and learning dimension through case studies is known to be an extremely accurate channel. Unfortunately, this methodology has some weaknesses, such as avoiding inter-firm, inter-sector, and inter-country analysis. Thus, when we decided to empirically construct a capability score through employing the Technology Index or to perform the Principal Component Analysis, we took advantage of the opportunity to compare countries' level of industrial capabilities in all the industrial sectors or in only one sector. Even if we could not capture neither changes in TCs (as data for only one year were available) nor the underlying learning processes and the paths of TCs' accumulation (available through case studies), we have been able to highlight many firms' efforts (education, skills, and training) due to build capabilities, albeit limited to basic technical functions. As expected to be extremely influential, we placed emphasis on highlighting firms' linkages with foreign sources of knowledge. Important dependence with external linkages emerged, with the only exception being the Brazilian strong National System of Innovation in some specific sectors. Among firms' characteristics for building TCs, firm size and foreign ownership have been confirmed as relevant ones in the three countries.

The reciprocal relationship between firms' TCs and the probability of exporting was also introduced in this research. Through the years, many literature contributions have been trying to disentangle the causality direction of this relationship, without reaching any definitive conclusion. We preferred to assume the reciprocal causality in this relationship, and to focus on evaluating it over the three studied countries. The evidence confirmed the hypothesis that TCs and exports mutually influence each other, but only in Brazil and Chile. In Argentina, in particular, large firms exert high levels of TCs (as showed in their TI) without reaching external markets. Further research is advisable to understand the main motivations, as well as to evaluate the influence of meso and macro factors.

Also through the years, there has been a radical evolution in the concept of innovation, moving from the Linear Model of Innovation towards a more comprehensive and complex vision such as the Systemic view. Different methodologies were proposed in the attempt to unravel a measure for innovation. In line with a narrow vision of innovation, some studies focus on inputs (the presence of the R&D department, R&D investments, etc.); while others are concentrated on outputs (such as patents, scientific citations, etc.). Under a broader view, the Systemic approach is especially useful to analyse innovation, as it takes account of firms' diversity, the complexity of their learning processes, and their different development paths.

Among different Systemic approaches, we selected the Sectoral System of Innovation (SSI) approach to analyze the food processing sector. Linkages and institutions were then highlighted and firms (as systems of a lower order) were put at the fulcrum of the entire system. Firms emerge as innovators because they have support from the system (strong relationships within networks, helpful institutions, etc). Again, size emerged as a fundamental factor for innovation in this SSI, even if small firms may overcome size's limitations through strong linkages (joint ventures) or cooperative actions. The connection with foreign sources of knowledge was found crucial for Argentinean and Chilean firms. Indeed, the increasing level of sophistication of this sector creates state of the art technological requirements, which are mostly not provided at the local level. Only Brazilian firms remained as the exceptions, relying mostly on their local National Systems of Innovation.

We also included institutions in our analysis, as the third building block. The institutions consistently play a crucial role, in particular due to the increasing level of sophistication and quality requirements of the food processing Sectoral System of Innovation which clears up every assumption of simplicity in natural resource-based sectors. We have focused on influential aspects regarding institutions' conditions and obstacles, which we found extremely influential for a highly-regulated sector such as food processing. Having applied all the pertinent caveats (related to the unavailability of important information), our results gave evidence that few variables of the SSI can increase the probability of innovation.

The last part of this dissertation meant to split TCs and to separately consider R&D, recognized as a crucial factor for innovation. This part of the study regards only one country: Brazil. There is wide consensus among different authors that Brazil still needs more R&D investments to foster innovation. Our contribution expected to go one step further, and analyze the complementary role of R&D with the other TCs for the introduction of new products and new processes.

It seems clear that the process of innovation in industrializing countries is different from the industrialized ones: the former group performs mostly incremental innovation. This may be in part the insight that process innovations are the most frequent ones in Brazil. In this sense, the evidence can probably suggest that Brazilian firms' efforts have been generating incremental changes, rather than generating new products because the way to introduce new products to the market is still difficult to achieve. Generating new products rather than new processes would require the strong push of R&D investments.

The positive results of our empirical model of two waves of surveys, one before and one after the Innovation Law, give indications about the complementary role of the different TCs, the R&D stock, and the R&D spillovers in fostering innovation. The "supportive structure" of TCs plus the positive and significant coefficients for the spatial knowledge spillovers, confirm the importance of firms' efforts to increase the probability of introducing new products and processes within the same UFe. Even if we can not strictly relate the positive signals to the Innovation Law, as the process of innovation usually requires many years, we can anticipate from our results that firms are obtaining positive effects from their investments in TCs, and in particular in R&D. Despite low public expenditures and innovation programs benefiting only a few firms, it seems that the innovation goals tend to be met in Brazil during the studied years.

And this is especially true for foreign-owned firms, which appear to be the most interested in engaging in innovation.

Finally, the processes of learning and innovating are extremely path-dependent; interruptions may create several delays while trying to engage them again. Thus, uncertain macroeconomic conditions and unhelpful institutions are unlikely to contribute to stimulating firms' indigenous efforts in building TCs to reach foreign markets or to innovate. Stronger links within the systems will also facilitate the process of creating a diversified, technologically advanced, and innovative industrial sector in these countries.

We conclude answering our research question, confirming that TCs contribute to exports, especially if efforts are not limited to basic TCs' levels allowing firms to compete in external markets. Especially in a context of uncertainty, firms, our main actors, pursue their technological objectives with "bounded rationality". However, it is a matter of fact that within a technologically changing context, investing in TCs and, in particular, in R&D, becomes an indispensable aspect for achieving innovation. We would like to express our explicit recognition about the increasing role played by the innovation system and, in particular, by institutions. We intend further research focused on the impact of contextual conditions (market failures, financial access, and other countries' idiosyncrasies) on firms' decisions to innovate.