Sectoral System of Innovation in Brazil: Reflections about linkages and the accumulation of technological capabilities experienced by SME suppliers to the aeronautic industry

Rosane Argou Marques[1]
L. Guilherme de Oliveira[2]

1. Introduction:

Since the end of the 1990s, Brazilian government policies have given incentives to strengthening linkages between firms and the science and technology infrastructure (research institutions) for promoting innovation and, consequently, for improving the country's competitiveness. The Brazilian government put forward innovation as the focus for policies when launched in 2004 the actual "Industrial, Technology and Trade Policies". Since then, Government agencies and research institutions have increased their role of articulating, modelling programs, financing and diffusing technological knowledge, especially for the segment of small and medium-sized firms (SMEs).

This set of industrial and S&T policies has a different focus when compared to those implemented by the military government (1960s-middle 1980s) and even after that phase, during the 1990s, when the government decision in relation to an explicit industrial policy was "not having an industrial policy is better". The military government had given a strong role for multinationals and state government firms as the primary sources of technology transfer to the local SMEs development. These policies have followed the international path in terms of objective, which was import substitution industrialization; although there are several differences among countries in the way they have been implemented. Some general examples of these differences can be observed when comparing the South Korean policies for industrialization during the 1970s and 1980s and the Brazilian ones.

South Korean policies followed the Japanese by controlling imports and stimulating exports; regulating capital and technology transfer from abroad; investing in increasing the number of engineers; and giving incentives to the development of technological capabilities in Korean firms. Large private Korean corporations had an important role in the Korean policies.

Brazilian policies were towards incentives for increasing foreign direct investment, building up industrial sectors in order to be self sufficient and creating government owned firms in strategic areas. There were also investments in the education system and in research institutions, as well as research and development activities at the government owned firms. The government owned firms and multinational corporations played an important role in building up a diversified industrial system. These firms have focused mostly in the Brazilian internal market and little in exports.

In an attempt to understand the role of national buyers, foreign buyers and research institutions (universities and technological centres) to Brazilian SMEs development, this

[1] Consultant at the Brazilian Agency for Industrial Development – ABDI (www.abdi.com.br). Contact details: roargou2003@yahoo.com; rosane.marques@abdi.com.br.
[2] Professor at the University of Brasilia (www.unb.br). Contact details: lgoliveira@unb.br.

paper explains the differences in activities carried out among them to the accumulation of technological capabilities experienced by these SMEs. The study makes the connection between activities undertaken and their impact in terms of technological change implemented and level of technological capability acquired by the SMEs. Additionally, it also distinguishes this connection over time, aiming at identifying if there were any accumulation of technological capabilities experienced by the SMEs. The main question is whether there are any differences in the role of the national and foreign buyers compared with research institutions to the accumulation of technological capabilities or not.

This issue is particularly addressed in the aeronautic sector because it is one of the most innovative and robust in the country - this sector was responsible by 3.1% of the Brazilian total exports in 2005, which was US$118.308 million (FOB). Moreover the Brazilian Aeronautic firm, Embraer, is one of the largest passenger airplane manufacturer worldwide with focus on commercial, executive and defence aviation. . Embraer was founded in 1969 by the Brazilian military government and was managed by the militaries until 1994 when it was privatised. Although it is successful in achieving international competitiveness on its specific market segment for regional jets flying from 45 to 108 passengers, Brazil has not being able to consolidate the supply chain of Embraer within the national borders. There are few Brazilian firms supplying to Embraer and to some of the foreign first tier suppliers of Embraer. In fact, the import content increased from approximately 68% in the 1980s (Dagnino and Proença, 1989) to approximately 95% in the 1990s (Bernardes, 2000a). Therefore, there is a question about how the local Brazilian suppliers are maintaining themselves in the competitive supply chain of Embraer. The findings show that they are improving their innovative capabilities in two directions: by strengthening their basic innovative capability regarding production processes and, in few cases, by upgrading to intermediate and advanced levels of innovative capability. The relationship with Embraer, foreign buyers and Brazilian research institutions are the main sources of knowledge for the technological learning experienced by these Brazilian suppliers that are “surviving” in the supply chain of Embraer.

The structure of the paper is as follows. We examine the literature about system of innovation and technological capability accumulation in the next section. Following that, the Brazilian Aeronautic Sector is briefly described in section 3 and the method is explained in section 4. Then, reflections about the case of Brazilian small and medium size firms (SMEs) accumulation of technological capabilities are made in section 5 and final comments are in section 6.

2. Sectoral System of Innovation and Technological Capability: analytical framework

2.1 The System of Innovation Approach

Systems of Innovation are the network of government and non-government agencies, science and technology institutes, educational organisations, and firms, among other organisations, which flows influenced the direction and extent of innovation. The country’s macroeconomic and industrial policies, international regulations, market governance, and socio-cultural institutions influence the network dynamism and trajectory. The interaction between the former and the latter has influenced knowledge accumulation and learning processes in firms (Nelson and Winter, 1982; Freeman, 1987; Nelson and Rosenberg, 1993; Cooke et al, 1997;

Hodgson, 1999). For understanding this issue, many authors have focused in distinct but inter-related areas of systems of innovation. Some of these areas are related to technological, sectoral, national, regional, financial, and political, among others, systems of innovation.

It worth to mention that the analytical framework utilised in this paper focuses on examining the evolution of a sector, specifically its dynamics and transformation over time, regarding to technological development and to linkages among actors. This approach refers, thus, to the sectoral system of innovation idea. Although many researches have been done about this theme, less comprehension exists on the relation among actors in a sectoral system and technological capabilities accumulation (Malerba, 2002).

Before focusing on the sectoral system of innovation, it is relevant for the debate to make few considerations about technological change and the broad system of innovation literature. First, the theory that technological change is not an isolated process emerged as an attempted to explain innovative behaviour and the consequent technological capabilities accumulation and evolution in firms. Second, technological change is a consequence of the capability of firms in managing and generating innovation as well as in acquiring and diffusing technological knowledge (Freeman, 1987). In fact, the development of such capability is a process that requires that a given firm interact with other firms, research institutions, universities and funding institutions, among other organisations. Third, government policies have an important role in regulate and co-ordinate the pace (quantity) and nature (quality) of the development of technological capabilities. This explains partly the differences of industrial development between countris, regions and sectors; other factors that may influence the differences are the specific endowments and characteristics where firms are located (De Ferranti and Perry, 2002). Differences between the three aspects of technical evolution turn on to influence the trajectory of countries for catching up industrialized countries (Viotti, 2002; Freeman, 1987).

Generally, researchers focus their analysis in two ways. First, they observe differences among countries and regions (national or regional systems) regarding the type of exported products, investments in R&D, investments in education and training, science and technology capabilities, industrial structure, and patents, among other variables (Viotti, 2002; Cassiolato and Lastres, 1999; Cooke et al, 1997; Patel and Pavitt, 1994; Nelson and Rosenberg, 1993; Lundvall, 1992; Freeman, 1987). Second, they examine technological diffusion and development within industrial networks (technological or sectoral systems) (Malerba, 2002; Breschi and Malerba, 1997; Carlsson, 1995; Carlsson and Jacobson, 1994).

Viotti (2002) considers that industrializing countries are adopters of technological knowledge from developed countries and their firms may develop incremental innovations according to their capabilities to do so. However these firms are not developing innovations in the same sense that Lundvall (1992) or Schumpeter (Malerba, 2002) defined. In fact, Viotti refers that innovation in these countries are not really innovation to the world market but they are adaptations to attend the specificities of industrializing countries He compares the case of South Korea and Brazil and concludes that the former is an active learning system and the later is a passive learning system. Active learning system is characterized by the capability to improve and adapt technologies while a passive learning system is characterized by the capability to adopt technologies.

The conclusion that the Brazilian System of Innovation as other Latin American countries are not innovative is supported by other researches. Cassiolato and Lastres (1999), Katz (2000, 2001) and Bernardes (2000) examined the technological behaviour of national and foreign firms and the influences of macroeconomic policies and industrialisation strategies defined by governments on this behaviour. Their common argument is that the Brazilian system is fragmented lacking long term industrial policies. Moreover, they refer that local firms have lacked innovative capabilities to succeed in competing in the world market.

Although there is lack of explicit long-term industrial policies, some researchers refer that the Brazilian System of Innovation is heavily influenced by the government development policies (Oliveira, 2005; Marques, 2004; Cassiolato and Lastres, 1999. Dahlman and Frischtak, 1990). Particularly, industrial structural changes resulted from Import Substitution Industrialisation policies maintained and strengthened the role of imported technologies and subsidiaries of foreign firms in the indigenous technological development. Dahlman and Frischtak (1990) observed that by 1960 more than 50% of the total goods manufactured in Brazil were produced by subsidiaries of foreign corporations. They also refer that the government create the research infrastructure to improve technological capabilities and develop a local supply chain to support the production facilities of foreign subsidiaries and national state-owned firms. More recently, Quadros et al (2001) and Costa and Queiroz (2002) argue that local foreign subsidiaries accounted for the largest share of private R&D activity in Brazil, which activities concentrate in the adaptation of products and processes to the local endowment. According to them, there has been a ‘moderate’ improvement in Brazilian firms’ technological capability after the Brazilian government shift from Import Substitution Industrialisation policies to Liberalisation policies during the 1990s, although local subsidiaries of foreign firms are still important innovators.

2.2 The Technological Capability Approach

More specifically to the firm level, another relevant literature regards learning and technological capability accumulation experienced by firms in industrialised countries. This literature highlights the trajectory of capabilities accumulation during the industrialisation phase focusing in the idea that technological change is endogenous or internal to the firm. Moreover, learning dynamics does not have only an endogenous own character but it has also elements of capturing external innovation through technology transfer, among other forms. In this way, efforts for technological adaptation associated to internal learning processes act upon the rhythm of acquisition of competencies, which can occur due to the characteristics of the external technology transferred (Oliveira, 2005; Fransman, 1984).

Research about technological capabilities accumulation is based on the evolutionary perspective of innovative efforts undertaken by firms. Since the 1980s this perspective has been developed considering firms as differing and dynamic organisations as well as stores of knowledge (Nelson and Winter, 1982). The evolutionary perspective also considers that firms evolve over time when they attempt to adapt themselves to their environment. This adaptation process has implications to the path of technological capabilities accumulation, which is related to the main characteristics of the innovative activities within firms, being uncertain and path-dependent on their knowledge base. Following this perspective, technological capabilities refers the dynamic and competence building activities firms undertake to generate new products, processes and services.

There are a variety of definitions for technological capability. Earlier studies consider technological capability as the systematic efforts for acquiring knowledge to improve production capacity (Katz, 1976). Other studies refer to the "capacity to manage technology and to implement technical change" (Bell, 1984:189). Some others include in the concept the ability of individuals, and infrastructure and activities undertake to implement changes in production and techniques (Figueiredo, 2003, referring to the studies of Bell, 1982; and Scott-

Kemmis, 1988). There exist some concepts that limit it to the ability of individuals and ignore their organisational context (Pack, 1987; in Figueiredo, 2001). Broader than Pack's definition, Enos (1991) refers to the technical knowledge necessary to achieve a common organisational objective that is embodied in the mind of engineers and technicians. Both definitions focus heavily on individuals as the locus of technological capabilities neglecting important organisational aspects that these capabilities integrate (Figueiredo, 2001).

In fact, based on previous studies, most literature about industrialising countries refers to technological capabilities as the ability to absorb, use, adapt, improve and change existing technologies. This ability involves the effective use of technological knowledge in production, investment, and innovation (Westphal, Kim and Dahlman, 1985). A central role is given to firm's in-house technological learning efforts to master new technologies, adapting them to local conditions, diffusing, and exploiting them by exporting (Lall, 1992). At this stage, it is important to make the distinction between types of technological capabilities that refers to distinct processes of learning.

In developing a framework for distinguishing between the forms of technological development experienced by South Korea, Westphal, Kim and Dahlman (1985) refer to three types of technological capabilities: production, investment and innovation. Production capability consists in the ability to operate production processes and adapt them to changing market circumstances. Investment capability refers to the skills for expanding and establishing new production facilities. Innovation capability consists in the ability to carry out activities for creating and implementing changes in techniques and organisational processes. They argue that technological development is costly because it requires stable and long term investments in skills and technological knowledge as well as improvements in organisational processes for learning to adapt imported technologies.

Drawing on Westphal, Kim and Dahlman (1985), Lall (1992) developed a framework for explaining firm-level differences in technological capabilities. The framework considers technological capabilities as divided in two types: investment and production, which innovative activities vary according to the degree of complexity from simple routine to adaptive and innovative. Adding to previous work, Lall argues that production capability is not only the ability to operate and improve imported production techniques but include the firm's in-house efforts in engineering for absorbing technologies, as well as linkages with other organisations. Linkages capability refers to the ability to transmit technological information and receive it from other organisations, such as suppliers, consultants, customers, service firms, and universities. These linkages are supposed to assist the firm to improve its productive efficiency and also the diffusion of technologies (Lall, 1992).

Kim (1997) also examined the process of technological capabilities accumulation experienced by Korean firms developing a "learning model" of acquisition-assimilation-improving foreign technologies. He considers technological capability as the ability of firms to utilize technological knowledge in an efficient manner in order to assimilate, use and adapt existing technologies. It has three main elements: production (management, engineering and repair and maintenance); investments (training, project development and implementation); and innovation (basic and applied research, development of new products, processes and services). The accumulation of technological capabilities took place in Korean's firms from imitation of foreign technologies, such as through reverse engineering and technology transfer, to innovation based on firms' internal efforts to develop and produce new products to the market.

Based on this research, more recent studies examined technological capabilities in a different spectrum: from the analysis of internationalisation of innovative capabilities (Ariffin, 2000) to explaining the differences between the process of accumulation in firms (Figueiredo, 2001). Drawing on Lall (1992) and Bell and Pavitt (1995), among others, Ariffin (2000) and Figueiredo (2001) consider two types of technological capabilities according to the activities for generating and managing technical change undertaken by firms: routine capability and innovative capability.

Routine capability refers to the firm's ability to utilize knowledge, technologies and undertake activities in distinct functions: product, production and organisational processes. Innovative capability permits the creation, modification or improvement of these functions. In fact, their routine capability refers to the first level of technological capability, defined by Lall (1992) as, experienced-based capability. Innovative capability, according to Lall, refers to the second and third levels of complexity, defined as, search-based and research-based. This distinction is important for explaining the path of technological capabilities accumulation experienced by firms in industrialising countries, which are building up capabilities from routine to innovative levels.

The literature reviewed so far analyses technological capabilities accumulation by basically examining distinct aspects of learning efforts undertaken by large firms, which are national champions, foreign subsidiaries, state-owned firms or recently privatised firms that are acquiring foreign technologies. These firms have to actively invest in the development of skills, knowledge and experience for learning and consequently building up technological capabilities. Their learning efforts change over time according to the technological complexity of products and production. This literature thus highlights the importance of deliberately invest in learning to build up technological capabilities. It does little, however, to discriminate the dynamic process of technological capabilities accumulation in small and medium size firms supplying to complex system manufacturer, as it is the aeronautic industry located in an industrializing country.

2.3 The Analytical Framework

Based on the literature reviewed, the broad analytical framework used for organizing the reflections about the innovative behaviour of Brazilian firms supplying to the Aeronautic Sector is shown in figure 1. At the centre of our reflections we consider the relationship between technological change (left side) and technological capability accumulation (right side). In fact, technological change is related to the level of technological capability of firms and to their linkages with other firms and research institutions (Lall, 1992; Fransman, 1984).

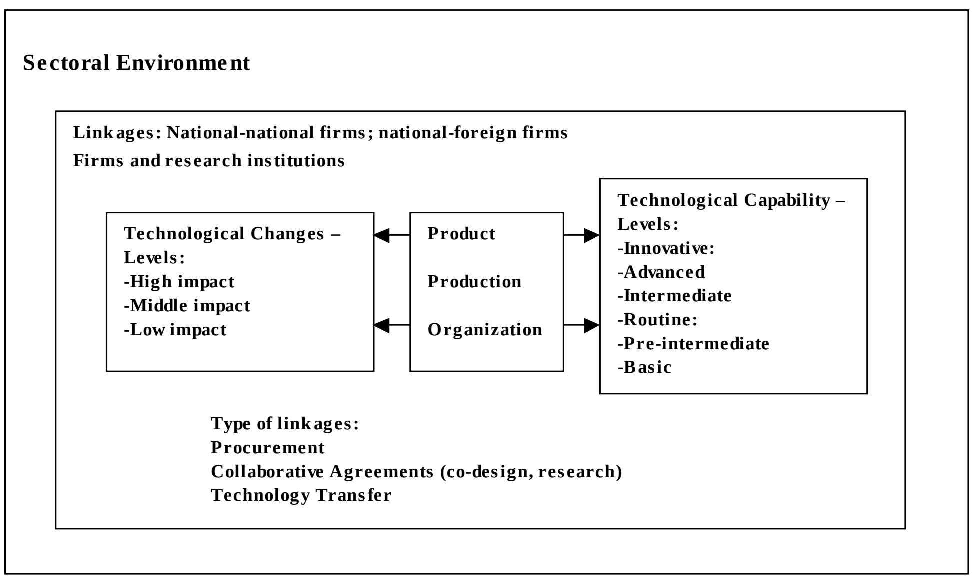
We consider in the paper, domains and levels that are relevant to the analysis of technological change and technological capability in the Brazilian Aeronautic Sector based on interviews and visits to firms, and on previous research (Oliveira, 2005; Marques, 2004; Bernardes and Oliveira, 2002; Bernardes, 2000, 2000a and 2000b; Frischtak, 1994 and 1992). The domains considered in the framework are product, production (process and equipment-related), and organisation of project management and design procedures.

Particularly, technological change consists of the introduction in the firm of technology embodied in the three domains (based on Bell and Pavitt, 1993). It can be related to the introduction of completely new technologies to the firm or to adaptations in the already existent product, production and organisational processes. This research classification is thus based on three levels of impact of the change in the firm (see Annex 1). The incorporation of substantially or completely new technologies in any or all of these three domains belongs to high-level impact. Changes incorporated in product, production and organisation for improving and upgrading the already existent technologies refers to middle-level impact. Finally, the duplication of technologies already in utilisation by the firm associates to low-level impact. It is important to stress that the changes may be inter-connected in the sense that a change in product may influence changes in production, which may call for changes in organisational processes. This inter-connection has not been explored in this paper.

Technological capability is defined as the ability of firms to manage and generate technological changes, i.e. their ability to innovate (Bell, 1984). The domains are product-centred, production (process and equipments), and organisational processes (project management and design procedures). Product-centred technological capability consists in the ability of firms to innovate in product design, specifications and quality. Production technological capability is classified in two domains: production processes and production equipments (machinery, equipments and software). Organisational centred technological capability regards the ability of firms to manage and generate changes in project management and design procedures.

Technological capability is classified in two levels: routine technological capability and innovative technological capability. Routine technological capability is the ability of a firm to utilize and adapt knowledge to implement changes in the distinct domains, which has two levels: basic and pre-intermediate (see Annex 2). In fact, this level is related to the production capability of firms, whereas innovative technological capability permit to create, modify or improve techniques. There are two levels for the latter capability: intermediate and advanced.

Figure 1 – Analytical Framework



Moreover, we examine some aspects of the Brazilian Aeronautic System of Innovation, which are historical development of the sector in terms of government support, launch of new products, and linkages among actors in the system. Particularly regarding to the classification of linkages, we consider it may be: procurement of services and goods; collaborative agreements for generating technological changes; and technology transfer.

3. The Brazilian Aeronautic System of Innovation

The Brazilian Aeronautic Sector is one of the most important high technology sectors in the country. The evolution of this sectoral system of innovation was examined in Marques (2004), which set out the background for the development of this section. Moreover, the main objective here is to examine how the Brazilian aeronautics has been developed since the foundation of Embraer in 1969. Using a historical approach, this section will give an overview of the steps followed by Embraer to become the world third producer of regional jets seating from 45 to 108 passengers. Therefore, section 3.1 briefly explores important features in the period pre-foundation of Embraer (before 1969). Then, section 3.2 examines the main characteristics of the three phases in which has been possible to identify more explicit industrial development policies: (i) starting-up (1969-1978); (ii) seeking the international market (1979-1994); and (iii) post-privatisation of Embraer (1995-2002). Finally, the general market characteristics are described in section 3.3.

3.1. The Brazilian Aeronautic Sector in the period before 1969

The period before 1969 can be examined taking in consideration three important periods of development of the Brazilian Aeronautic Sector. The first period was during the 1910 to 1930-decades. According to Dagnino and Proença (1989), the first and remote step for developing an aeronautic sector in Brazil was in the 1910-decade when *Santos Dumont*, a Brazilian industrialist, developed the first heavier-than-air flying machine. Although some investments were done in this period, Brazil lacked engineering and technological capabilities, as well as the government policies, that such industry required. Then, the efforts done had not resulted in any significant development of the Brazilian Aeronautic Sector.

The second period was during the Second World War (1935-1945). Brazil, as an allied of the USA, functioned as a producer of attack aircrafts. During this time, the American Air Force trained Brazilian pilots and formed aeronautic engineers for helping in the production of aircrafts. Brazil produced approximately one aircraft/day for the USA during this time (Dagnino and Proença, 1989). Although more government efforts were done than in the first phase, they were not sufficient for setting up the basis for the sectoral economic growth. The lack of technological and engineering capability to design and produce airplanes in Brazilian continued. At that time, the production was restricted to light aircrafts for utilization in agricultural matters.

Therefore, the Brazilian Army Force decided to create an aeronautical institute to form highly qualified engineers for supporting the infant aeronautic sector. The Technological Institute of Aeronautics (ITA) was founded by the end of the 1940-decade, which marked the beginning of the third period. ITA was founded with support of MIT and NASA. ITA formed approximately two hundred engineers until 1970 but the most part were contracted for working in other sectors due to lack of companies to contract them in the aeronautics (Bernardes, 2000a; Dagnino, 1993; Dagnino and Proença, 1989).

During the 1950-decade, the Brazilian Army Force was aware that it was also necessary the creation of a research centre for applying aeronautic engineering knowledge to the development of a "Brazilian aircraft" that could fly according to the particular endowment and characteristics of the Brazilian territory. They founded the Aerospace Technical Centre (CTA) that absorbed ITA and developed other institutes for aeronautic research. The main research project at CTA was for the design and production of a 19-seats aircraft. The Brazilian Ministry of Aeronautics contracted an entire research group from Germany that worked with Brazilian engineers from ITA with the aim of developing such aircraft. The first prototype flew in 1959 and further improvements were necessary. In 1969, the project was then concluded and the first aircraft called Bandeirante could be produced. This group of researchers founded the first state-owned aircraft producer in Brazil in 1969, Embraer, with support of the Brazilian Ministry of Aeronautics (Bernardes, 2000a; Dagnino, 1993; Dagnino and Proença, 1989).

3.2. The Brazilian Aeronautic Sector from 1969 to 2002

The **starting-up phase** begun in 1969 when the Brazilian Ministry of Aeronautics founded the Empresa Brasileira de Aeronáutica S. A. Embraer. The aircraft producer was created as a spin off of the CTA, with the objective of supplying the Aeronautic Command with parts, components, and training and attack aircrafts (Dagnino and Proença, 1989; Coutinho and Ferraz, 1993; Bernardes, 2000a). According to Frischtak (1994:602), 'although the production of airplanes in Brazil dates back to 1910, when the first monoplane was built in the country, the development of the Brazilian passenger aircraft industry can be equated with the development of Embraer'. The main civil aircraft produced during the 1970s was a nineteen-seat light twin-engine turbo propeller (Frischtak, 1992; Bernardes, 2000a).

The Ministry of Defence was the main buyer and also gave strong tax incentives and subsidies to Embraer for developing production and technological capabilities to manufacture the nineteen-seat aircraft (Dagnino and Proença, 1989; Coutinho and Ferraz, 1993; Bernardes 2000a). These incentives were oriented for financing (through subsidies and tax exemption), marketing (through procurement and protectionism) and developing technologically (through the creation of special decrees for technology transfer and supporting research). In this first ten years of existence, the main market was national.

According to Dagnino and Proença (1989), although the Ministry of Defence had heavily invested in the creation of a national aircraft supply chain (aircraft assembler and suppliers), approximately 68% of parts, components and sub-systems of aircrafts produced were imported. Nevertheless, some suppliers had developed capacity from the production of parts and components to the production of small aircrafts (1-10 seats), such as Aeromot (located in Porto Alegre, State of Rio Grande do Sul) and Neiva (Botucatú, State of São Paulo). This development was possible due to the Ministry of Defence special programs for 'nationalisation' of aero parts (systems, structural parts and other components). However, according to interviews at the Institute for Development and Coordination of the Aerospace Industry (IFI), low production scale, high quality, and high development costs of aero parts influenced the production concentration at the aircraft producer itself. Few local supplier firms had developed the capacity to produce parts and components and they had relied heavily on technological transfer from CTA through IFI consultancy. Therefore, the most part of aero parts were imported in the end of 1978.

The **seeking international market phase** corresponds to an increase in exports of small-body aircrafts (10-30 seats) that happened after the American market de-regulation in 1978 (Coutinho and Ferraz, 1993). Therefore, the second phase corresponds to the period when the market changed from National to foreign. A thirty-seat advanced twin-engine turbo propeller aircraft was the main commercialised product during this phase. According to Frischtak (1992:13) 'At end 1990, [the thirty-seat aircraft] market share in the 20-45 seat category was

25% worldwide, just slightly below of its major competitor (the SAAB SF340). In the U. S. market, [it] had the dominant position in that year in terms of the total number of aircraft in service, again for the 20-45 seat category'.

The launching of the eight-seat twin-engine turbo propeller pressurized aircraft in 1979 is the starting point of this phase in the development of the Brazilian civil aircraft manufacturing (Frischtak, 1994; Bernardes, 2000a). This aircraft was the first one entirely undertaken by Embraer, for which the market was not mainly the Brazilian Air Force but American large corporations. It was a business aircraft designed to attend the American market. The aircraft producer undertook the product development, financed it, and designed and manufactured the pressurized system (one of the main innovations in this model) (Frischtak, 1994). It was the first aircraft developed using the concept of communality or 'family'. The second in the family was the thirty-seat aircraft, which was launched in 1981 for supplying the USA and Latin American market (Frischtak, 1992).

The 'nationalisation' of aero parts program that begun in the starting-up phase stopped almost completely in this phase. The phase of 'denationalisation' had begun as well as the aircraft producer focus on technological development at international market standards. Another important characteristic of this phase is the increasing reliance on imported systems, structural parts, among other parts, components and sub-systems. The new market demanded many improvements in digital technologies, new materials, sophisticated software, among other technological developments that the local suppliers could not adopt. Local suppliers had lacked government incentives and economies of scale for this technological upgrading. And, the Ministry of Defence have reduced the budget to IFI, which decreased significantly IFI support for the technological development of local suppliers.
The recession in the international civil aircraft market and the Brazilian government decreasing procurement and subsidies had been the main factors affecting the financial crisis of the aircraft producer in the beginning of the 1990s (Bernardes, 2000a; Bernardes, 2000). The company was thus privatised in 1994. Many small and medium size local Brazilian suppliers exited the market due to the economic recession in 1990-1994.

The most important products in the **post-privatisation period** have been the ERJ 145 jetliner and the ERJ 170 jetliner. The ERJ 145 jetliner has the basic platform of the thirty-seat advanced turbo propeller but incorporates new technologies in avionics, propulsion and aerodynamics, and was launched in 1995. The ERJ 170 jetliner first 'roll-out' was in November/2001 and the first flight was in 2002. Both aircrafts have been developed within the concept of family or commonality (Oliveira and Bernardes, 2002).

Summarizing, the Brazilian government has supported the civil aircraft manufacturing in all stages of its development basically through (Green, 1987; Bernardes, 2000a): (1) research and development policies; (2) joint government-private ownership; (3) protection of home markets; (4) export development policies. However, at least one important question is: did the government efforts be successful in terms of increasing international competitiveness of the civil aircraft manufacturing?

3.3. General characteristics of the Brazilian civil aircraft market

According to Dagnino (1993), Donângelo et al (2000) and Bernardes (2000a) the Brazilian international civil aircraft market is mainly the U. S. and Europe, although there are investments for increasing the participation of China and Asia. During the 1970s and 1980s the main market however was the Brazilian, which imports were restricted by the "Law of

Similars" (Chapter III, Section V of Decree-Law Nº 37, as implemented by Decree Nº 61,574 of October 20, 1967) that was part of the Import Substitution Industrialisation policies (Green, 1987). Then, Embraer was granted the monopoly for production and commercialisation of aircraft turbo-prop with more than 8 seats. Piper was the only foreign competitor of Embraer that was selling in the Brazilian market due to a licence agreement signed between them before the Law of Similars was implemented. During this period, the main competitors of Embraer in the U. S. and Europe were: De Havilland, Cessna, Fairchild, Piper, Saab, BAe, Dornier, Fokker, and Canadair.

By the end of the 1980s and during the 1990s, some civil aircraft manufacturers exited the civil aircraft market, such as BAe, Cessna, Saab, and Fokker, among others; while others merged or were acquired, such as Fairchild-Dornier, and Bombardier-Canadair. Fairchild-Dornier filed for bankruptcy in 2002. Since the 1990s, the main international competitor of Embraer is Bombardier-Canadair that is called Bombardier Aerospace. Bombardier is the third largest world producer of regional jets while Embraer is the world's four largest with 45% share of the regional jet market in 2000. The fierce competition between the two companies led them to complain at The World Trade Organization on unfair subsidies given by the Brazilian and Canadian governments. Bombardier complains that Embraer's jets are less technologically advanced then their jets and is doing well in the market due to the lower labour costs, cheap Brazilian currency, and the Brazilian government subsidies. Embraer complains that Bombardier's jets are subsidised by the Canadian government low loan rates. The WTO complains started in approximately 1998 and is still going on (Padgett, 2003).

The main civil aircraft models manufactured by Embraer are shown on table 1. Therefore, Embraer's market segment ranges from small turbo-prop seating 8 to 30 passengers, which are the models developed during the 1970s and 1980s; and medium size jets seating 35 to 108 passengers. They fly specifically short hauls or regional routes, mainly linking hub routes and small airports. As*Vc is the performance indicator that represents the number of seats (As) multiplied by the speed (Vc). It is considered by Mowery and Rosenberg (1981) an important indicator of performance development. Table 1 show that there is a substantial increasing in the aircraft performance since the launch of the ERJ 145 jetliner.

Table 1 – The Evolution of Aircraft Models Produced in Brazil

Year (First plane flew)	Model	Seats	Altitude (feet)	Speed (km/h)	Characteristics	(As*Vc)
1972	EMB 110 Bandeirante	19	22,500	413	Light twin turboprop	7847
1979	EMB 121 Xingú	8	26,000	450	Twin turboprop pressurized	3600
1983	EMB 120 Brasília	30	30,000	555	Turbo propeller	16650
1995	ERJ 145	50	37,000	833	Twin turbofan (jet)	41650
1995	ERJ 140	44	37,000	833	Twin turbofan (jet)	36652

1998	ERJ 135	37	37,000	833	Twin turbofan (jet)	30821
2002	ERJ 170	70	37,000	870	Jet	60900
2004	ERJ 190	98	37,000	870	Jet	85260
2005	ERJ 195	108	37,000	870	Jet	93960

Source: websites - http://www.embraer.com, and http://www.airliners.net/. Information gathered in January 2001.

By the end of the 1980s, the Brazilian government started a process of opening up the national market and changed the macro policies from Import Substitution Industrialisation to Liberalisation. It reduced substantially the subsidies given to Embraer and there was no longer import restriction for small regional aircraft as it was in the previous period. Embraer, which was controlled by the Ministry of Aeronautics, was sold to private companies in 1994.

Nowadays, the main market of the Brazilian aircraft manufacturing is foreign, which accounted for approximately 72,5% of the turnover in the year 2000. AIAB (2001) observed an increase in the total exports from U$ 0,70 billion in 1997 to U$ 2,50 billion in 2000 (table 2). As a consequence, there is a rise in the participation of the aircraft industry in the Brazilian GDP, measured by the total turnover divided by the total GDP, which jumped from 0.29% in 1997 to 1.06% in 2000. Embraer corresponds to about 80% of the total Brazilian aeronautic sector.

The economic performance of Embraer has been positive since 1997: the turnover increased from U$0.29 billion in 1996 to U$4.6 billion in 2005. In fact, exports accounted for most part of the turnover that grew from U$0.13 in 1996 to U$3.2 billion in 2005. Following that growth, employment has increased from 3,849 people in 1996 to 12,622 people in 2005. Nowadays, Embraer responds for approximately 2% of the total Brazilian exports[3].

Embraer implemented many changes during the period 1996-2005. Important changes were concerned with management of project development, relationship with suppliers as well as procurement. At the same time, a reduction in production cycle or from starting production to the phase-out occurs from eight months in 1996 to five months in 2000 (Damiani, 2001). In this context, local suppliers, which have been mostly subcontracted for supplying pieces and parts, assembly jigs and tools and engineering projects, may accomplish with tidy delivery time and high quality standards. For doing so, they may accomplish with Embraer's technical, quality and financial requirements. The procurement unit is auditing the supplier once or more a year and monitoring the accomplishment with these requirements. Local suppliers are then implementing and correcting the suggested items in the auditor's report. Nowadays, the most parts of Embraer's suppliers are foreign: imports accounted for U$1.73 billion.

4. Research Methods

Firms were selected using purposeful sampling. As opposed to probability sampling, the logic and power of purposeful sampling is to select information-rich cases from which it is possible to learn about issues of central importance to the purpose of the research (Patton, 1990; Yin,

[3] Information gathered from Bernardes (2000a) and Embraer reports to investors at www.embraer.com.br in August 2006 .

1994). The main issue that this thesis is concerned with is accumulation of technological capabilities experienced by Brazilian SMEs in the Brazilian aeronautic sector. SMEs are firms with less than 500 employees as defined by the Brazilian Institute for Geography and Statistics (IBGE).

The selection of the local SME suppliers was done in two stages: the pilot phase and the main fieldwork. In the pilot phase, a catalogue of firms from the National Aerospace Industry Development and Co-ordination (IFI)[4], called CESAER 2001, were surveyed to produce/collect information about the composition of the Brazilian local suppliers in the civil aircraft industry. Thirty-one local Brazilian firms out of 98 were primarily selected. After that, the results were compared with the sample survey of a Brazilian research on the aeronautic system of innovation, co-ordinated by Roberto Bernardes, Jose E. Cassiolato and Helena Lastres, and financed by the Brazilian FINEP[5], and checked with Embraer's procurement unit and with Roberto Bernardes. Then, 12 SME suppliers of Embraer were selected for in house interviews and visits to their plant. Embraer and 5 subsidiaries of foreign first tier suppliers of Embraer were interviewed and visited. Based on the research interviews and double checked with Embraer, the production chain structure was built as showed in figure 2.

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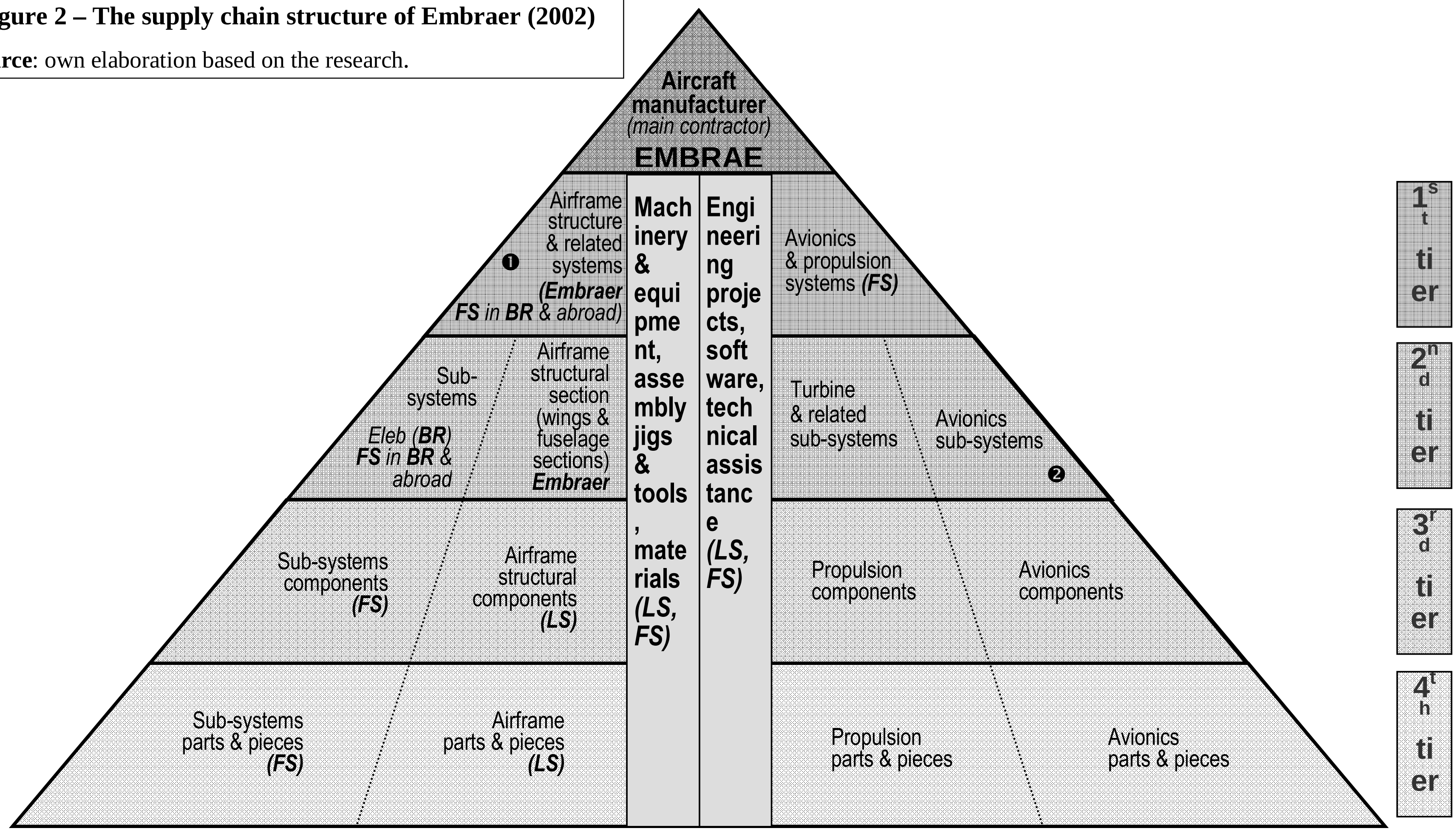
[4] IFI is an institute of the Technical Aerospace Centre –CTA.

[5] FINEP – Financiadora de Estudos e Projetos (Finance of Studies and Projects) is a foundation of the Ministry of Science and Technology (www.finep.org.br).

Figure 2 – The supply chain structure of Embraer (2002)

Source: own elaboration based on the research.



LS – Local SME Suppliers ***FS*** – Foreign Suppliers ***BR*** – Brazil

❶ Fuselage, energy system, landing gear, hydraulic system, interiors, environmental system, electric system

❷ Navigation, communication, surveillance, flight command

Embraer is the main buyer and aircraft system integrator, i.e. firms that design the product and integrate its components, which outsource manufacturing and design activities seeking to leaner their organisational structures. Outsourcing these activities requires close inter-firm interaction and co-ordination at the knowledge and organisational level (Brusoni and Prencipe, 1999). Few firms compose the first tier in this supply chain, which are foreign firms with the exception of Embraer that produces airframe structure. These first tier firms are joint developing the aircraft models with Embraer and are also system integrators. The only Brazilian supplier in the second tier is Eleb, a producer of landing gear sub-systems, which has participated in joint development projects with Embraer and foreign suppliers of Embraer. Local SME firms supplying in the chain are mostly in the third and fourth tiers, among the ones that are mainly supplying to all tier firms and are showed in the middle boxes in figure 2. They are all owned by Brazilian firms or individuals with the exception of Eleb, which shareholders are: Embraer (60%) and Liebherr Aerospace - Germany (40%).
The five subsidiaries of foreign suppliers located in Brazil are in the first tier supplying airframe structures and related systems, and propulsion system. Their activities in Brazil are mostly customer support and assemblage of airframe structural sections to Embraer. They were selected because their plants in Brazil resulted from the second Brazilian government efforts for "nationalisation" of the supply chain, which Embraer is responsible for undertaken efforts to attract foreign suppliers to locate in Brazil. The firms settled plants in Brazil are first tier suppliers that joint develop projects with Embraer. Their contact details were given by Embraer's technological development unit and double-checked with the procurement unit.

4.1. Brief description of the sample of suppliers

4.1.1 Local SME supplier firms

This section aims at characterising the local SME suppliers interviewed in terms of their ownership, period of foundation, number of employees, market characteristics and product characteristics. Brazilian firms or individuals own all SME suppliers, although there is one firm that is a joint venture between Embraer and the German Liebherr Aerospace.

The majority of local SMEs firms were supplying to the Brazilian market, particularly to Embraer and the Brazilian Air Force, which was approximately 80% of their market. There were two firms that entered the export market, which were only supplying to Embraer until the end of the 1990s. These suppliers were exporting landing gear, motor glider, spare parts to Embraer aircraft models EMB-120 Brasília, and engineering consultancy in design, production and assemblage of airframe structural sections, particularly fuselage sections.

.

Product characteristics

The majority of local SME suppliers were manufacturing fuselage parts and components (third and fourth tiers) using steel, aeronautic aluminium and composite materials, while two firms are producing parts to avionics in aluminium and composite material. The other parts and components supplied vary from nails and pieces to hydraulic components. One supplier firm produced landing gear utilising new composite materials and electronic components.

Assembly jigs and tools are utilised as support to the assembling of fuselage sections as well as to the integration of fuselages to the airframe. Jigs and tools are also made-to-order for supporting prototype tests. They were made in steel and had electronic components to adjusting the jig or tool to the size of the fuselage section and airframe.

Engineering projects and consultancy was based on mechanic and aeronautic engineering knowledge. Specifically, local SME suppliers were designing airframe structural sections, parts and components, as well as defining their production specifications. Particularly engineering consultancy was giving to foreign suppliers of Embraer in Europe about design definition and production processes, as well as support in the integration of fuselage sections to the airframe.

The software firm supplied enterprise resource planning (ERP), i.e. software utilised in the management of integration among all units of the firm, to a subsidiary of foreign supplier of propulsion system to Embraer. The development of the ERP was made in close integration with the customer as a team of technicians were working inside the customers' plant.

4.1.2 Characteristics of foreign suppliers located in Brazil

The main characteristics of the five subsidiaries of foreign suppliers interviewed are shown in the table below. The large majority were settled in Brazil in the period 1999-2001. They are assembling systems and airframe structures. They have also participated in the co-design arrangement with Embraer for developing the projects ERJ 145 and ERJ 170. Technical support to system integration in the airplane at the plant of Embraer was another activity undertaken by them. The subsidiary QF has not focused only in supplying to Embraer. In fact, this firm has overhaul and maintenance of turbines as the main market focus since it acquired the Brazilian manufacturer of engines called Celma. The Brazilian plant is one of the fewer GEAE that includes the development of processes for turbines maintenance.

The other interesting case is TF that produces airplane structural sections to Airbus airplanes in Brazil. This firm transferred part of its European manufacturing activities to Brazil. Although there are non R&D or design activities locally, it is working for the implementation minor improvement activities in accordance with quality and other exigencies of Embraer.

The other three cases are only assembling parts and components to the fuselage and interiors, as well as hydraulic system and flight controls, which are manufactured in their home countries. In fact, all subsidiaries had few Brazilian suppliers, which were mostly related to engineering services for fuselage structural assemblage and accomplishment with Embraer exigencies.

Table 2 – Characteristics of the subsidiaries of foreign suppliers of Embraer located in Brazil – 2002

Firm	Foundation	Activity in Brazil	Embraer Aircraft Model	Ownership	Employees (*)	Market
PF (First tier supplier – Airframe Structure)	2001	Assembly of interior compartments	ERJ 145 ERJ 170	100% USA	106	Embraer
QF (First tier supplier – Propulsion system)	1951 (Acquired by General Electric Aircraft Engines-GEAE/USA in 1992)	Overhaul, accessories and component repair of power plant – engines (Assembly and production of parts for engines before 1992 for the Embraer's military aircraft AMX)	AMX ERJ 170	99% GEAE USA 1% Brazilian Ministry of Defence	350	Brazil (including Embraer) Export
RF (First tier supplier – Hydraulic system; Second tier supplier – Flight control)	1999	Customer support for repairing and assembling hydraulic system, flight controls	ERJ 170	100% USA	12	Embraer
SF (Second tier supplier – Airframe Structural Sections)	2000	Assembly and repair passenger window transparencies	ERJ 145 ERJ 170	99% UK 1% USA	09	Embraer
TF (Second tier supplier – Airframe Structural Sections)	2000	Assembly structural parts and customer support	ERJ 145 ERJ 170	100% Belgium	99	Embraer

Source: own elaboration based on interviews.
Note: (*) Number of employees in November 2002.

5. Reflections about the accumulation of technological capability and the role of linkages

This section comments briefly the results of our fieldwork. Table 3 below classifies the SMEs according to the Annex 2. The results show that SME suppliers have mostly maintained themselves in the supply chain by using their already existent basic routine technological capability to implement technological changes. Fewer SMEs have upgraded to the pre-intermediate routine technological capability and even less moved to innovative intermediate. In fact, only one SME developed advanced innovative technological capability during the period 1970-2002.

Furthermore, all firms mastered basic levels of technological capabilities in all domains: product-centred, production (process and equipment-related), and organizational process (project management and design procedures). Most part of firms (Group 4) implemented technical changes utilising their existent basic routine technological capability, which associates to passive learning efforts. This means that they are able to manage the replication of specifications from customers, basic quality control, routine replacement of components in machinery, equipments and software, basic coordination of project development and basic routine design procedures. From the sample of twelve firms, one SME maintained its pre-intermediate routine technological capability, and three have accumulated technological capability in the period 1995-2002.

The three local SMEs that built up technological capability, which are classified under the headings of Groups 1, 2 and 3, had pro-actively invested in learning in order to manage and generate technical changes in different domains. These firms are compared below considering the domains of technological capabilities accumulation in the period 1995-2002. The firm considered in Group 1 is Firm 5 that built up advanced technological capability in product-centred innovation. From mid-1980s up to 1994, this firm acquired intermediate technological capability in product for developing landing gear to Embraer aircraft models. It had also managed tests for improving production process, moving from basic to pre-intermediate routine technological capability. During this period, efforts were made to improve the internal coordination of projects through managing team working, allowing the firm to master pre-intermediate level of technological capability in project management.

From 1995 up to 2002, Firm 5 had a pro-active learning behaviour by investing in in-house R&D and partnership with customers and universities/research centres for product development, among other learning activities. The firm had also improved technological capabilities from:

- pre-intermediate to intermediate in production process;
- pre-intermediate to intermediate in the organisation of project management;
- basic to intermediate in production equipment-related; and
- basic to intermediate in the organisation of design procedures.

Table 3 – Technological capability: number of firms by type and level

Technological Capability	Level / period											
	Advanced			Intermediate			Pre-Intermediate			Basic		
	1970-1980	*1981-1994*	*1995-2002*	*1970-1980*	*1981-1994*	*1995-2002*	*1970-1980*	***1981-1994***	***1995-2002***	***1970-1980***	***1981-1994***	***1995-2002***
Product	-	-	1	-	2	1	1		1	**2**	**7**	**9**
Production					-							
Process	-	-	-	-	-	1	-	2	3	**3**	**7**	**8**
Equipment related	-	-	-	-	-	1	-	1	1	**3**	**8**	**10**
Organisational processes												
Project management	-	-	-	-	-	1	-	1	-	**3**	**8**	**11**
Design procedures	-	-	-	-	-	1	-	-	-	**3**	**9**	**11**

The local SME considered under the heading Group 2 – e.g. Firm 1 – built up intermediate innovative technological capability in product and pre-intermediate routine technological capability in production process. In reality, Firm 1 developed the two seats airplane AMT 600 by utilising its intermediate innovative technological capability acquired in the period 1981-1994 when it received technology transfer while working in a government project for replacing training airplanes.

The other SME that built up pre-intermediate technological capability in production process was Firm 4, classified in Group 3. This firm undertook efforts for managing team working, training of employees and in-house tests for production process and product development since its foundation in 1995. It had also managed tests for assuring quality control in production and implemented an ERP computer system.

Considering the impact of technological changes implemented by the SMEs suppliers (table 4), all firms have implemented high-level. The technological changes were implemented mostly during the period 1981-1994 and 1995-2002. The latter was the period in which SMEs implemented high-level changes in all domains, although most firms implemented changes in product and production processes and equipments. It is important to say that two firms did not mention the implementation of any technological change in the period 1970-1980, while one firm implemented change high and middle levels in product in this period.

Table 4 – Number of firms implemented technological changes by type and level

Technological Changes	**Level / period**								
	High			**Middle**			**Low**		
	1970-1980	***1981-1994***	***1995-2002***	*1970-1980*	***1981-1994***	***1995-2002***	*1970-1980*	***1981-1994***	***1995-2002***
Product	1	3	**7**	**1**	3	**6**	-	1	**1**
Production									
Process	-	2	**9**	-	2	**7**	-	1	**3**
Equipment related	-	2	**8**	-	-	**5**	-	-	**2**
Organisational processes									
Project management	-	1	**1**	-	-	-	-	-	-
Design procedures	-	-	**4**	-	-	-	-	-	-

The research findings so far shows that there are differences in the level and domains of technological changes implemented by the SMEs compared to the level of capability accumulation. Particularly, local SMEs that maintained their basic routine technological capability implemented mostly changes high, middle and low levels in production processes in the period 1995-2002. These changes related to the implementation of ISO 9000 standards and quality assurance procedures to accomplish with either Embraer requests or with a government program for promoting exports. They have generated and managed the implementation of changes by contracting a consultancy firm to help them.

The local SMEs that moved to more innovative levels of technological capability implemented mostly high-level technological changes in product, production and organisational procedures. Particularly, those SME that achieved advanced technological capability in product implemented high-level technological changes in project management and design procedures, which was not observed in the other firms.

Moreover, the research findings suggest that differences among the four groups of SMEs refer to their market strategy. The group of SMEs that maintained their basic routine technological capability supplied mostly to Embraer, following Embraer requests and blue prints, whereas the other groups of SMEs also supplied to other customers, such as foreign firms and/or subsidiaries of foreign suppliers of Embraer located in Brazil. In particular, the SME that have built up advanced technological capability in product was largely affected by the development of Embraer itself. The accumulation of technological capability experienced by this SME was influenced both by its internal learning efforts and by its relationship with other firms and universities and research centres, as well as its participation in government programmes.

According to the interviews, two firms did not implement any significant technological change in the period 1970-1980, while the one firm that did implement change in the period did so in product. In the following period (1981-1994), the amount of firms that did not implement changes was as follow:

- five firms - product and production processes;
- seven firms - production equipment-related;
- eight firms - organisation of project management; and
- nine firms - organisation of design procedures.

Regarding the period 1995-2002, all firms implemented at least technological changes in product and production equipment. The amount of firms that did not implement changes were:

- one firm - product;
- two firms- production process;
- eleven firms - project management; and
- eight firms - design procedures.

Table 5 summarizes the direction to which the 12 sampled SMEs accumulated technological capabilities associating them to the level of technological changes implemented. The shadow boxes show that the majority of the firms implemented changes high, middle and low levels utilising the already existent basic routine technological capability. The four firms that moved to other levels of technological capabilities implemented technological changes levels high and middle in product and production process and equipment. Just one firm improved to intermediate technological capability in the organisation of project management and design procedures in the period 1995-2002.

Table 5 - Classification of firms according to technological change and technological capability: level and period

Technological change (domain/level)	**Technological Capability Level / period**											
	Advanced			**Intermediate**			**Pre-Intermediate**			**Basic**		
	1970-1980	*1981-1994*	***1995-2002***	*1970-1980*	***1981-1994***	***1995-2002***	***1970-1980***	***1981-1994***	***1995-2002***	***1970-1980***	***1981-1994***	***1995-2002***
Product												
High	-	-	**Firm 5**	-	**Firm 5**	**Firm 1**	**Firm 1**	-	**Firm 4**	-	**Firm 10**	**Firm 2 Firm 6 Firm 7 Firm 10 Firm 11**
Middle	-	-	-	-	**Firm 5**	-	-	-		**Firm 1**	**Firm 1 Firm 8**	**Firm 3 Firm 8 Firm 9 Firm 10**
Low	-	-	-	-	-	-	-	-	-	-	**Firm 1**	**Firm 9**
Production												
Process												
High	-	-	-	-	-	**Firm 5**	-	**Firm 5 Firm 8**	**Firm 1 Firm 4 Firm 8**	-	-	**Firm 2 Firm 3 Firm 7 Firm 11 Firm 12**
Middle	-	-	-	-	-	**Firm 5**	-	**Firm 5**	-	-		**Firm 3 Firm 7 Firm 8 Firm 9 Firm 11**
Low	-	-	-	-	-	-	-	-	-	-	**Firm 6**	**Firm 4 Firm 7 Firm 9**

Continuation Table 5

Technical change (type/level)	Technological Capability Level / period											
	Advanced			Intermediate			Pre-Intermediate			Basic		
	1970-1980	*1981-1994*	*1995-2002*	*1970-1980*	*1981-1994*	*1995-2002*	*1970-1980*	*1981-1994*	*1995-2002*	*1970-1980*	*1981-1994*	***1995-2002***
Production												
Equipment related												
High	-	-	-	-	-	-	-	**Firm 8**		-	**Firm 10**	**Firm 1** **Firm 2** **Firm 3** **Firm 4** **Firm 8** **Firm 9** **Firm 11** **Firm 12**
Middle	-	-	-	-	-	**Firm 5**	-	-		-	-	**Firm 6** **Firm 7** **Firm 10**
Low	-	-	-	-	-	-	-	-	-	-	-	**Firm 2** **Firm 9**
Organisational processes												
Project management												
High	-	-	-	-	-	**Firm 5**	-	**Firm 5**	-	-	-	**-**
Middle	-	-	-	-	-	-	-	-	-	-	-	**-**
Low	-	-	-	-	-	-	-	-	-	-	-	**-**
Design procedures												
High	-	-	-	-	-	**Firm 5**	-	-	-	-	-	**Firm 7** **Firm 9** **Firm 12**
Middle	-	-	-	-	-	-	-	-	-	-	-	**-**
Low	-	-	-	-	-	-	-	-	-	-	-	**-**

Figure 3 compares the direction and extent to which the SME suppliers have accumulated technological capability. The direction may be to managing and generating high-level impact technological change by maintaining the existent technological capability at one side; or upgrading the technological capability while managing the implementation of higher levels of technological change. The findings show four groups of SMEs:

- Group 1: One firm that achieved advanced technological capability at least in one area, i.e. product-centred, production (process, equipment-related), or organisational processes (project management, design procedures), and implemented high-level technological change in at least one of these areas.
- Group 2: One firm that built up intermediate technological capability in at least one of those areas explained in Group 1, and implemented high-level technological change in at least one of those areas.
- Group 3: Two firms that built up pre-intermediate technological capability in at least one of those areas explained in Group 1, and implemented middle-level technological changes at least in one of those areas.
- Group 4: Eight firms that implemented at least low-level technological changes in one of those areas explained in Group 1, and maintained basic technological capability.

Figure 3 - Groups of SME suppliers in the Brazilian civil aircraft industry

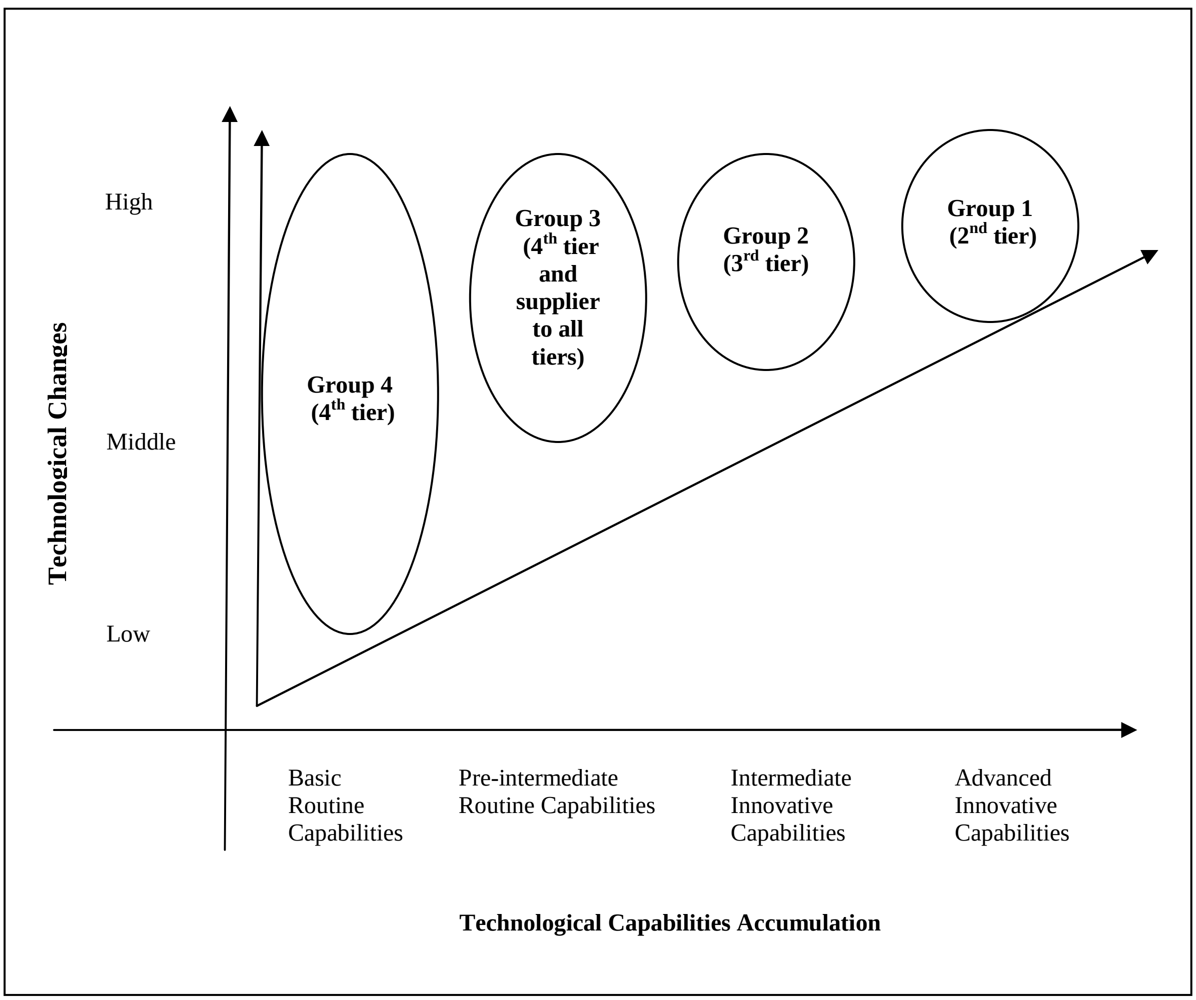


Table 6 shows the characteristics of linkages for each group of SME suppliers taking into consideration the sources of external knowledge, and linkages types, activities and impact.

Table 6 – Comparison between the groups of SMEs and linkages

	Group 1	Group 2	Group 3	Group 4
Sources of external knowledge	Universities/research centres; Embraer and foreign customers	Universities/research centres; Brazilian Air & Navy Forces; Suppliers;	Brazilian and Foreign customers, suppliers, Internet	Embraer, consultancy, supplier
Types of linkages	Collaborative agreement, technology transfer and procurement	Collaborative agreement, technology transfer and procurement	Procurement	Procurement
Activities/ Linkages	Joint product development with customers; contracting research and tests at universities and research centres, hiring experts, training outside	Contracting university tests and experiments; informal tests at foreign customers plant	Hiring experts; eventual training outside; informal contacts with university and research centre	Hiring experts, informal contacts with university and research centre
Impact of linkages	Contributing to investments in research and development of product; and implementation of technological changes in project management and design procedures; Proposals from suppliers contributing to the implementation of changes in production	Blue prints/specifications from the engine supplier and tests at universities contributing to the implementation of technological changes in product	Technical support from customer contributing to the implementation of tests and prototype activities that impact changes in product and process	Blue prints and specification from customers and suppliers contributing to the implementation of all technological changes

In fact, linkages experienced by firms in Group 3 are similar to firms in Group 4, whereas the differences arise in the activities and impact of the linkages. First, firms in Group 3 are hiring experts, undertaking training outside the firm. Furthermore, their customers and suppliers helped in the implementation and management of technological changes, while specific work in the customer plant was undertaken as well as their technical support at Group 3 plants. Second, SMEs in Group 4 had trained employees in-house on-the-shop floor since their foundation up to 2002. In some cases, Group 4 SMEs have employees working inside Embraer plant. Embraer trained these employees in areas related to the product and production quality assurance, among other topics as safety and confidentiality. In this sense, Embraer was transferring technological information to local SME suppliers at the extent of their involvement working inside Embraer plant. Other research finding worth to mention is that local SMEs classified in Group 4 relied heavily in the technical assistance given by Embraer and CTA for the generation of technological changes more than the other groups.

Differences between them and Group 1 are that this group was actively learning from Embraer and foreign buyers by participating in joint product development activities, which contributed to the implementation of technological changes mostly in product, project management and design procedures, and to the building up of advanced innovative technological capability. Other important linkages are with Brazilian and foreign universities and technological centres for researching and training employees. As in the case of Group 2, it relied more in the acquisition of blue prints, specifications and technical assistance from foreign buyers, engine supplier and universities than to Embraer. Moreover, it has received technology transfer from foreign firms when participating in the Brazilian military government offset programs[6].

Particularly related to inter-firm linkages, although it is difficult to separate the influence of linkages with Embraer and other firms, the research findings suggested that linkages between Group 1 and Embraer contributed largely to the implementation of technological changes in product, production, and organisational processes. Moreover, its linkages to foreign suppliers of Embraer and foreign buyers contributed to the accumulation of innovative technological capabilities for generating changes in product and organisational processes. It is worth to mention that Embraer itself particularly influenced collaborative agreements between Firm 5 and foreign firms. Technology transfer from foreign buyers to Firm 5 had also an important impact in the innovative capability accumulation and it was related to some of the high-level technological changes implemented by this firm. In fact, the technology transfer was negotiated by the Brazilian military government in the end of the 1970s up to middle 1980s in offset programs.

The distinction between Group 1 and Group 2 in terms of their participation in government offset programs refers to the extent the government funded and negotiated the technology transfer. In the case of Group 2, the government negotiated the technology transfer of seats production that was a field in which the firm had already technological capability; whereas in the case of Firm 5 the government funded and negotiated technology transfer for design and production of parts and components an area in which this firm lacked capability.

6. Final comments

To understand the technological capability accumulation and the role of linkages with national and foreign buyers, and research institutions in the Brazilian aeronautic sector involves a difficult exercise for perceiving changes in the innovative environment and in the supply chain. Initialy, the development of this sector was tied to the strengthening of CTA. In the period pre-privatisation of Embraer, it was very important the participation of the national government through its technological policies for developing research capacity in the aeronautic field. The creation of a R&D environment together with tax incentives and government procurement turned possible the accumulation of technological capabilities experienced by Embraer, Firm 5 in Group 1, and Firm 1 in Group 2. In fact, it was in the mind of the military government the importance of building up an environment that makes possible development and manufacturing of airplanes, particularly by creating a group of actors linked to: i) R&D in the space field; ii) R&D in critical technologies; iii) competence building; and iv) support to the certification of aerospace products and production.

[6] The offset programs of the Military government refer that foreign firms supplying to the government may transfer technology to Brazilian firms in accordance to the specific procurement agreement.

At the same time, continuous R&D for developing new airplane models was undertaking by Embraer which turned possible the accumulation of expertise by the firm about all systems integrated in the airplane as well as about its suppliers. It is worth to remember that some important suppliers of technologies to Embraer were Aeromacchi, Northtrop e Piper. Partnership with these firms influenced Embraer innovative capability accumulation and, particularly, competence building to manage joint projects. However, the Brazilian macro economic crises lead the government to follow the international liberalization policies and, following that, the privatisation of Embraer.

The organisation of Embraer's supply chain changed drastically after its privatisation in 1994. The economic crises and the privatisation lead to a new behaviour of the firm regarding project management and the supply chain organisation. In fact, Embraer elaborated complex management architecture for moving up with its projects of jetliners. The management architecture involved reducing the number of first tier suppliers, and increasing collaborative agreements (co-design and risk sharing) with fewer strategic foreign suppliers. The Brazilian SME suppliers have not been incorporated in collaborative agreements, with the exception of the firm in Group 1.

Finally, the study concludes that the interaction between SMEs and research institutions for implementation of technological changes that were new to the firms driven these SMEs to invest in engineering and testing/searching activities, inexistent activities before the interaction. On the other hand, the activities undertaking with Embraer were more related to technological upgrading making use of existing knowledge base rather than for accumulating technological capabilities, with the exception of Firm 5. The interaction between SMEs and foreign buyers was also possible due to the existing knowledge base of the SME. These foreign buyers considered very important the tacit knowledge accumulated by these SMEs in the specific areas in which they were supplying to Embraer. The experience as suppliers of Embraer was very important to the foreign buyers, which were supplying systems and sub-systems to Embraer. Therefore, the foreign buyers had little influence in the technological changes the SMEs implemented or in their accumulation of technological capabilities, with the exception of Firm 1 and Firm 5. Finally, it is important to emphasize that the few SMEs suppliers of Embraer that built up technological capability from basic production to more innovative levels (including learning by searching and by interacting with research institutions) constitute a special group of firms: they have, over time, been strategic to Embraer, engaged in military projects and very competitive in terms of international markets.

In fact, the type of activities undertaken by the SMEs differed according to the novelty of the technological change to the SME. The completely new technologies called for interaction with research institutions (universities or technological centres) and searching and testing activities in-house. Following that, product, production and organizational changes related to the improvement of existing technologies called for doing and adapting activities through close interaction with Embraer (national buyer) and foreign buyer. Embraer had also played an important role in training employees of the SME suppliers. The results suggested there is a strong relationship between the novelty of the technological change to the firm and the type of activities undertaken with research institutions, national buyer and foreign buyer.

Finally, we suggest that government policies for upgrading Brazilian SME suppliers in their supply chain positioning should take into consideration instruments to strengthening their technological capabilities. This is particularly relevant to the actual characteristics of the strategies of Embraer for managing the relation with suppliers. In fact, the strategies moved forward for managing suppliers increased the internationalisation of procurement and participation in product development as observed in chapter 3. Furthermore, foreign suppliers are sharing product development activities as well as the necessary investments and returns. This behaviour poses another question referring to the lack of financial capabilities of Brazilian SME suppliers for sharing risks and product development. Following that, we also suggest that policy instruments should focus in stimulating the upgrading in the SMEs to completely new and more advanced technologies while forcing them to strengthening linkages with research institutions and implementing engineering, project management and design procedures.

Concluding, the Brazilian aeronautic system of innovation generally follows the loose characteristic of the national system of innovation, although there are few exceptions of successful firm specific cases of tide linkages with research institutions, national and foreign buyers, participation in government programs and innovative capability accumulation. Government policies, thus, should also focus on the diffusion of the innovation culture in the sector through the successful cases of SMEs that accumulated innovative capability and not focus only at Embraer or at foreign buyers.

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Annex 1 - Technological changes: level and domain

Level of Impact	Technical Changes				
	Product	*Production*		*Organisational Processes*	
		Process	*Equipment-related*	*Project Management*	*Design Procedures*
High	Completely new product	Completely new process, for example, cell manufacturing, just in time, and standards (ISO),	Completely new machinery, for example, 5 axes CNC machinery and laser machinery, new software for measuring	Completely new project management process, such as implementation of integrated project management and co-design	Completely new software for design, such as adoption of CATIA software, computational fluid dynamics
Middle	New materials; new specification in measures, resistance, durability and/or speed	Implementing quality control step, test step, or another step in the already existent process,	Upgrading in the specifications of the already existent machinery and software	Implementing new steps in the already existent project management process	Upgrading in the already existing software, or/and implementing new steps in the already existent design procedure
Low	Same product with improved painting and/or polishing	Organizing the already existent process	Same machinery and equipment	Organising the already existent project management process	Organising the already existent design procedures

Source: Based on Bell and Pavitt (1993), and on the research.

Annex: 2 Framework for technological capability accumulation

Capability Level	Technological Domains and Related Activities				
	Product-centred	Production		Organisational Processes	
		Processes	Equipment Related	Project Management	Design Procedures
Innovative Capability					
Advanced	In-house R&D or/and in partnership with customers/suppliers and/or research institutes/universities substantially changing product design and/or specifications;	In-house process R&D, and/or in partnership with customers/suppliers and/or research institutes/universities	In-house R&D for improving performance of machinery and equipments and for their new components; design and manufacture (machinery and/or equipments); software for attending specific demand	In-house development of integrated project management techniques, involving the units: product development, production, finance, and marketing, among others	Managing the development of co-design techniques involving the participation of customers/suppliers
Intermediate	Product engineering activities; in-house design and prototyping activities	Engineering activities for adapting processes; systematic reverse engineering; continuous process improvement	Managing the development of specific machinery and equipment definition for production by an OEM, including monitoring tests and training operators; preventive maintenance	Team working for improving management of multi-firm projects and integration of product components	Team working to improve design procedures
Routine Capability					
Pre-Intermediate	Managing tests and experiments in-house to improve product quality	Managing tests and experiments	Managing tests and experiments for implementing minor adaptations in machinery and equipments and/or software, adjusting to new raw materials or to improve performance under international certification (ISO 9000); own breakdown maintenance	Team working for improving quality in the internal coordination of projects	Managing quality control procedures in design
Basic	Replicating specifications; routine quality control; attendance of customer's requirements	Routine production coordination across plant; basic quality control; replicating techniques	Routine replacement of components in machinery, equipments; routine software upgrading; participation in installation and performance tests	Basic coordination of project development for accomplishing with deadlines; routine management procedures	Basic control of documentation; routine design procedures (basic CAD)

Source: adapted from Lall (1992), Bell and Pavitt (1993), Ariffin (2000), Figueiredo (2001), and based on the research