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Competitive Dynamics and Technological Strategies in the Regional Aircraft Industry: an evolutionary perspective

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Abstract

The paper develops an analysis of the competitive dynamics of the regional aircraft industry. Initially, a conceptual framework for analyzing this subject is extracted from the evolutionary literature of Schumpeterian tradition. Then, the analysis tries to identify technological innovations and the institutional changes with disruptive impacts to the technological trajectories faced by regional aircraft builders. Subsequently, the recent evolution of competitive dynamics is analyzed with basis on those concepts, emphasizing the process through which the firms have tried to build competitive advantages based on deliberate strategies of innovation. After that, some comments about the impacts of those strategies to the concentration of the regional aircraft industry are developed as well as some prospective possibilities about the evolution of that industry in the near future.

Key words: regional aircraft industry, innovative strategies, product life cycle

Resumo

Este artigo analisa a dinâmica competitiva na indústria de jatos regionais enfatizando a concorrência schumpeteriana. Inicialmente é desenvolvido um referencial teórico evolucionário que permita caracterizar a dinâmica competitiva nessa indústria. Em seguida, são apresentados alguns paradigmas e mudanças institucionais citados na literatura que influenciaram as trajetórias tecnológicas das construtoras. Na seqüência, a recente evolução da dinâmica competitiva é analisada a luz dos conceitos elaborados na primeira parte, destacando o processo através do qual as firmas têm tentado construir vantagens competitivas baseadas em estratégias deliberadas de inovação. A parte final traça alguns comentários sobre os impactos dessas estratégias na concentração da indústria de jatos regionais e possibilidades a respeito da evolução dessa indústria.

Palavras-chave: indústria de jatos regionais, estratégias de inovação, ciclo de vida do produto

Introduction

High levels of industrial concentration characterize the aircraft industry. The civil aircraft market is usually segmented into two great categories, in accordance with its purposes: corporative and commercial markets. Commercial aircrafts are used by air carrier companies to the transportation of passengers and cargo. Corporative aircrafts are used in the segment of executive air transportation. In those segments, different institutional contexts might have distinct impacts to the trajectories of firms and technologies. The idiosyncratic nature of innovative strategies adopted by aircraft builders also affects directly this dynamics. In this context, the competitive process is also strongly influenced by strategic policies and by complex regulatory issues inherently associated with the aircraft industry.

Currently, the biggest aircraft builders are Boeing, Airbus, Embraer and Bombardier. The regular air carrier market can be divided into two categories: general and regional. The aircraft models used in the main routes of continental or intercontinental transport have usually a capacity above 120 passengers. These routes are usually connected to regional routes, in which regional aircraft models operate between a central point and a periphery of locations through a hub-and-spoke structure. The two main aircraft companies specialized in the market for regional aircrafts are the Brazilian Embraer and the Canadian Bombardier. Their main models are regional jets with a capacity between 50-122 seats. However, some of the models constructed by Embraer (E-Jet 190 and 195) concur in the same segment of aircraft constructed by Boeing (717-200 and 737-600) and Airbus (A 318).

Some concepts developed by the evolutionary literature of Schumpeterian tradition can be used to analyze the dynamics of competition in the regional aircraft industry. This theoretical framework seems particularly useful to discuss the complexity inherently associated with that industry, where technological innovations introduced are usually project intensive, requiring the development and integration of different systems and components. In this context, innovative strategies – as mentioned in the typology constructed by Freeman and Soete (1997) – are usually modulated by the evolution of technological trajectories and by the capabilities progressively accumulated by industrial firms through different learning mechanisms (Malerba, 1993). However, there are also some structural determinants of the evolution of technological trajectories that might affect this process, specially the gradual definition of a dominant design to regional jets, in the sense analyzed by Utterback and Suarez (1993). Facing those forces, the idiosyncratic posture of industrial firms might intensify the uncertainty inherently associated with the innovative dynamics. The capacity to identify attractive opportunities generated by the evolution of technological trajectories and the stimulus and obstacles associated with each institutional context tend to be reflected in the spectrum of technological strategies adopted by industrial firms, from explicitly offensive postures to defensive or imitative strategies. The aggregated evolution of those strategies tends to be reflected in a general pattern, explained by the theoretical concept of product life cycle developed by Hirsch (1965) and Freeman and Soete (1997). The sequential phases of this cycle indicate how technological innovations affect and are affected by the characteristics of the competitive environment.

The paper develops an analysis of the competitive dynamics of the regional aircraft industry. Initially, a conceptual framework for analyzing this dynamics is extracted from the evolutionary literature of Schumpeterian tradition. Then, the analysis tries to identify the technological innovations and the institutional changes with disruptive impacts to the technological trajectories faced by regional aircraft builders. Subsequently, the recent evolution of competitive dynamics is analyzed with basis on those concepts, emphasizing the process through which the firms have tried to build competitive advantages based on deliberate strategies of innovation. After that, some comments about the impacts of those strategies to the concentration of the regional aircraft industry are developed as well as some prospective possibilities about the evolution of that industry in the near future.

Theoretical Background

According to the Neo-Schumpeterian tradition, the competitive dynamics can be connected to the perspective of appropriation of quasi-rents generated by technological innovations, through a process conducted by mechanisms of selection that prevails in each market. This dynamics involves the process through which the industries emerge, evolve and decline along time. In order to systematize the theoretical framework that orients this perspective, Malerba and Orsenigo (1996) articulate three key-concepts. The concept of "industry dynamics" can be associated with the industrial basis that are affected by the introduction of a disruptive innovation into the market, involving the industrial demography, the distribution of firms according to its size and the prevalence of relevant asymmetries among them in terms of technological capabilities and economic performance. The concept of "structural dynamics" can be articulated to some "driving forces" that define how the industrial structure changes along time. Specifically, these forces involve the idiosyncratic character of the innovations introduced into the market, their connection to entry and exit movements of firms and their impacts over the competences previously established. These forces can also generate a progressive change of the main determinants of competitive advantage in the industry. Finally, the concept of "structural evolution" can be associated with some general pattern of change of the industrial structure modulated by the impacts of the introduction and diffusion of technological innovations. Through this concept, it is possible to articulate the concept of technological trajectories to the evolution of industrial structure, permanently affecting the basis through which the "industry dynamics" evolves along time.

Some methodological principles are implicit in this perspective. First, inter-firms asymmetries and the diversity of competences and strategies seem to be particular relevant to the generation of a “structural dynamics” modulated by the impacts of technological innovations. Second, a variety of learning mechanisms – internal and external to the firms - tend to operate in each industry, affecting and being affected by the nature of technological trajectories that define how the industrial structure evolves along time. Learning mechanisms involve internal and external sources of knowledge, which is generated, appropriated and integrated through cumulative processes (Malerba, 1992). Third, the multiple and systemic interactions between technological strategies, competence building processes and different mechanisms of learning define the dynamics of innovation at the firm level. Fourth, a dialectics between permanent forces of turbulence and strong patterns of regularities also defines how the industrial structure evolves along time. Fifth, in order deal with the complexity of this process it seems useful to aggregate to the analytical framework some concepts constructed to capture sector specificities of industrial dynamics.

Contrasting with the orthodox perspective, the Schumpeterian analysis defines the concurrence as a process intrinsically dynamic. In this sense, endogenous forces – among which technological innovations is the critical element – define how the competitive dynamics works (Possas, 2002). Technological innovations have simultaneously broader and specific impacts, affecting some general organizational patterns as well as the determinants of competitive advantage in each industrial context. The compulsory movement of industrial firms to guarantee their survival involves stimulus to perform innovative efforts that are intrinsically uncertainty, in order to generate temporary extra profits. In this context, situations of transitory monopolies tend to be the norm, being completely consistent with the general pattern of competitive dynamics. According to this view, if innovative strategies are well succeeded, monopolies can be sustained for variable periods of time. Kupfer (2002) stress that, in this context, the determinants of monopolistic positions tend to be more articulated to the strengthening of innovative capabilities than to the searching of productive efficiency trough a process o cost minimization.

From these general arguments, some specific concepts can be extracted from the evolutionary literature to discuss the specific nature of the competitive dynamics and the impacts in terms of the technological strategies adopted by industrial firms in the regional aircraft industry. Starting from the typology constructed by Freeman and Soete (1997), innovative strategies can be summarized in six categories: offensive; defensive; imitative; dependent; traditional; opportunistic[1]. Offensive, defensive and imitative strategies are usually associated with uncertainty institutional and technological contexts. Offensive strategies are oriented to the search of technological leadership as

[1] The intensity of different categories of innovative efforts – involving aspects such as basic and applied research, experiments, design engineering, quality control, technical assistance, patents, technical and scientific information, technical training, technological planning – can be articulated to characterized those strategies.

a way to increase firm's market-shares, through the appropriation of economic quasi rents that come from technological novelty and originality. Internal innovative activities are very R&D intensive, being oriented to a long run planning. Firms that opt for the implementation of such strategies might have the capacity of mobilizing a high-specialized contingent of scientists and technical staff, in order to deal with the sophisticated knowledge that might be mobilized and integrated to generate technological innovations.

A firm with a defensive strategy usually tries to follow closely the movements of the offensive firms. Among the factors that might explain this behavior, we can mention: 1) the aversion to the natural risks associated to the exploitation of technological originality; 2) the possibility of exploiting the errors and misunderstandings of offensive innovators; 3) the limited technological capabilities to perform basic and applied research required to generated disruptive innovations; 4) competitive advantages associated with the availability of technical skills in engineering and marketing activities, permitting to perfect the production and to exploit more effectively the market. Defensive innovative strategies are very common in structured oligopolies, involving different forms of product differentiation. The higher is the innovative rate, the prompter and faster might be the reaction of defensive firms, in order to reach and overtake the firms with offensive strategies. Activities related to the management of scientific and technical information seem also to be particularly relevant to reach these goals.

Imitative strategies are adopted by firms that do not pursuit to achieve the technological leadership, following the aggressive innovators with some distance and exploiting the possibilities opened by the natural process of technological diffusion through R&D adaptive efforts. However, as stressed by Tigre (2006), theses strategies usually involves a compression of profit margins, especially when the products became less differentiated along time. To avoid the risks of loosing competitiveness, these firms should be capable of monitoring technological information and of implementing quality control procedure that might compensate the competitive disadvantages they faced in the marked. All these strategies – offensive, defensive and imitative – are based on search procedures, requiring the mobilization of financial and human resources to perform R&D activities and the development of complex mechanisms of technological learning, not only inside but also outside the limits of the firm.

In the other three strategies mentioned in Freeman's typology (namely dependent, traditional and opportunistic), R&D efforts tend not to be a relevant aspect of firms´ strategies. In the dependent strategy the innovative efforts adopted by firms might be subordinated to the policies implemented by other firms that are more innovative, with the former becoming a kind of technological satellite of the latter. The dependent firm tends to be involved in subcontracting industrial relations, performing innovative efforts according to the stimulus and demands generated by more innovative firms. Sometimes, this kind of technological dependency requires the increase of collaborative efforts between those agents. In the traditional strategy, innovative efforts tend to be particularly limited, being restricted to the gains generated by learning by doing practices (Arrow, 1962) that occur in the productive orbit, with the firms assuming a relative passive attitude in which the innovations are incorporated only when they are extensively available in the marked. Finally, in the opportunistic strategy the technological efforts - particularly those related with the management technical and scientific information and with long run planning - are oriented to the identification of dynamic technological niches with attractive market potential. Opportunistic strategies try to exploit the potential of these niches very rapidly, before they become attractive to the technological leaders of the industry. These strategies are much more based on the capacity of monitoring the impacts of rapidly technological changes than on the mobilization of a significant amount of resources to R&D activities.

The spectrum of strategies mentioned in Freeman's typology might be articulated according to the evolution of the technological trajectory in a specific industry. The aggregated evolution of those strategies could be articulated to the general pattern proposed by the theory of product life cycle (Hirsch, 1965; Freeman and Soete, 1997). According to this analytical framework, a general pattern involving technological rivalry and competitive pressures might explain how technological innovations are generated and diffused along time. Specific mechanisms of cumulative learning operate in the different phases of this cycle, requiring the previous accumulation of technological competences by industrial firms, through a strongly path-dependent dynamics (Malerba, 1992). The dynamics of the life cycle of a product might be represented by a logistic "S-shaped" curve (as proposed by Pearl's Law). According to the pattern represented by this curve, technological improvements tend to be hardly obtained in the earlier stages of the cycle, being subsequently accelerated and then progressively reduced. This dynamics result in a tendency of reducing the pay offs of the investments associated with the introduction of incremental innovations along time (as proposed by Wolff's Law).

The characteristics of technological patterns in each phase of the product life cycle directly affect the innovative strategies implemented by industrial firms. In the first phase of the cycle, there is an intense concurrence based on product differentiation, which contributes to the decrease of the price elasticity of demand. In their seminal analysis of product life cycle, Utterback and Suárez (1993) stress that, in the early phase of the cycle, the design of the product is still not well defined, stimulating a restricted movement of entrance in the industry. In this phase, the limited rate of diffusion tends to be reflected in the shape of the logistic curve. It is also very common the persistence of some volatility of the market shares in this phase, stimulated by the inadequate appropriability conditions of the innovations. Different mechanisms of learning among economic agents – particularly those that occur between producers and consumers of the innovations – tend also to be observed in this phase. Freeman and Soete (1997) emphasized that the initial investment and the experience required to generate technological innovations might not be a relevant restriction in this phase. On the other hand, the possibility of accessing the relevant knowledge and of exploiting technological externalities – especially those related with spatial location and spillover effects – tends to be very important. These aspects might limit the amount of resources effectively compromised to exploit the dominant technological trajectory, generating some kind of technological flexibility and compensating the risks associated with the uncertainty of market evolution.

When the cycle gains momentum, the rate of diffusion begins to accelerate stimulated by the knowledge progressively accumulated by economic agents (Malerba, 1992), contributing to the progressive definition of a dominant design. When this design becomes relatively well defined, the characteristics and norms of the production tend to stabilized, facilitating the search of complementary assets. The competition becomes to be increasingly based on cost efficiency, scale economies and on the continuous improvement of product performance. The dominant design is the result of cumulative technical experiments and of technological choices determined by market stimulus and by the natural evolution of technological trajectories. The consolidation of the dominant design might have a huge impact over the rate of technological advance, the industrial structure and the norms of the concurrence, becoming a key aspect of competitive dynamics.

The low exigencies observed in the easy entry phase of the cycle tend to be reverted with the consolidation of a dominant design, which increases the amount of investments and skills that might be retained by the firms to survive in the market. At the same time, the importance of local advantages and spillovers generated by scientific infrastructure tend to decrease. This tendency emerges because of the broadly technological diffusion, which reinforces the rigidity of organizational structures and stimulates the firms to concentrate their efforts in areas related to some core capabilities. Sometimes, this process can result in the generation of lock-in effects, with alternative designs being deliberatively excluded from the competitive dynamics. According to Vernon (1961), even with the increasingly standardization associated with the consolidation of a dominant design - which reduces technological uncertainties - the concurrence remains strongly based on product differentiation in the subsequent phase of the cycle.

In general, until the high growth phase of the product life cycle, the firms tend to adopt a wide spectrum of offensive, defensive and imitative strategies. When the cycle becomes closer to the maximum, the market structure is already consolidated. At the same time, innovation rates tend to stabilize, reinforcing the importance of a concurrence based on price efficiency, stimulated by the progressive decrease of price elasticity along time (Hirsch, 1965). The availability of capital funds to finance the investments also becomes a factor increasingly important to competitive dynamics. The market structure also tends to become much more concentrated, often involving bankruptcies, acquisitions and fusions among industrial firms. Along this process, the market structure might be accommodated, with distinct variants of technological trajectories being exploited by different firms. Some firms might take the lead of technological dynamics while others tend to become subordinated to the leaders, adopting dependent strategies.

Historical and Technological Briefing of the Regional Aircraft Industry

The emphasis on the characteristics and impacts of innovative strategies and the arguments developed by the theory of product life cycle provides an appropriate support for the understanding of the competitive dynamics related to regional jet industries in the past few years. Nevertheless, before developing the subject along the next section, it is convenient to present some trends, stylized facts and institutional events that have had influence upon the technological path of the aircraft industry in general, whose effect reverberated into the current format of the regional jets competition.

According to Rosenberg (2006), since the 20's decade, commercial aviation began to be structured as a product of public policies that led to technological progress and to the creation of the necessary infrastructure for airline operations. This period might be characterized as the *First Stage* of the development of aircraft industry. From 1934 on, a *Second Stage* began, being characterized by the vertical separation of aircraft production and air transport at the entrepreneurial level[2]. During the Second World War, commercial transport was practically extinguished; however, it was possible to exploit scaled economies and learning effects deriving from war efforts to produce aircraft for military purposes. This period is characterized as the *Third Stage* of the development of aircraft industry, according to Rosenberg's systematization. The *Fourth Stage* of the aircraft industry was initiated in the post-war period, being extended until the 70's. This period was marked by the revival of the commercial air transport and by the use of jet engine in commercial aviation[3], with the Boeing 707 release, in 1958, followed by the DC-8 release by Douglas and the Convair 880 release by General Dynamics. Nelson and Winter (2005) have stated that the advent of the two first models represented the beginning of a new product cycle in the commercial airline transport. The disposition of its two engines under each wing defined a pattern that was followed by the new models introduced in the market. In the 60's, the jet engine commercial market became to be controlled by General Electric and Pratt & Whitney. Its application in commercial airline transport was associated with the market withdrawal of other engine and aircraft manufacturers, in addition to the progressive decline of the commercial leadership of Douglas and Lockheed, which had been consolidated during the interwar period.

[2] The DC-3 was launched at that time (1936) in commercial transport. It represented the synthesis of the advances incorporated in a varied set of technology components and materials. Its operational cost was 60% lower than that of the Boeing 247, the most competitive model then, which had been released in 1933 (Rosenberg and Mowery, 1998).
[3] The Comet by De Havilland was the first commercial jet aircraft to operate in 1952. However, technical problems due to failure in foreseeing the fuselage metal fatigue during flights have caused many accidents, disabling the commercial use of the model.

The regional air transport started to stand out from 1978 on, as a result of the deregulation process (1975-85) occurred in the American[4] airline transport market, being also strongly stimulated by the effects of the two oil shocks (in 1973 and 1979). At that time, the airline infrastructure became to be much more detached, with the strengthening of *hub-and-spoke* structures which permits to exploit physical network externalities, enabling the use of regional aircrafts *(commuters)* based on smaller bodies *(narrow-bodies)*. Simultaneously, engine manufacturers strived to develop equipment with better performance well adapted to the needs of regional aircraft builders. It was the conjugation of these trends that contributed for the first release of Embraer in the American market in 1978.

The participation of the fuel cost in the expenses of airline companies operating with jet engines have raised from 12,7% (1970) to 20,5% (1977) and, later it was raised to 28,1% (1982)[5]. These events, combined with the deregulation of the American air transport in 1978, have dismissed the requirement of the use of large aircrafts in low traffic airlines, opening a vast market for the twenty-seat commuters, such as the Bandeirante produced by Embraer. As a response to the new competitive scenario, airline companies have modified their operating strategies in certain non-stop routes, replacing them by hub-and-spoke routes, which operate with a much more profitable occupation rate (defined as a *load factor* by the airline industry). This new configuration of the airline fleets has reduced the number of airports (-79%) attended solely by large aircrafts, while the number of airports attended solely by regional aircrafts (58%) has increased a lot between 1978 and 1982. The same phenomenon was observed in the airports that operated the two kinds of aircraft simultaneously. Dagnino (1993) points out that the greatest impact of the deregulation was observed in the thirty-seat or forty-seat aircraft category, which has grown 550% in the eight subsequent years after 1978.

The restriction on the fuel consumption imposed by the oil crises favored the Brazilian turbo propulsion aircraft model, when it was compared with its concurrent based on jet engine propulsion, making the Bandeirante a very attractive economic alternative, especially to small regional airline companies. Thus, the two oil crises have generated turbulences in the aeronautic market, restraining the possibilities for the use of jet engines in the regional segment. At that time, the jet engine technology generated expenses that hardly justified its wide use in regional routes. These facts also contributed to the success of the EMB-120 (Brasília), which was launched in 1985. Such incompatibility, however, started to change from the end of the 80's, when the effects of the oil crisis became to be progressively attenuated. Over that same period, many technological

[4] Locally, commercial regional transport was stimulated by the creation of the SITAR (Regional Air Transport Integrated System), in 1975. According to Bernardes (2000), the American market represented 60% of the world market in 1960.

[5] Air Transport Association of America, Inc., Aerospace Facts and Figures, 1983/1984, p. 98. In: The Competitive Status of the U.S. Civil Aviation Manufacturing Industry (A Study of the Influences of Technology in Determining International Competitive Advantage - NATIONAL ACADEMY PRESS WASHINGTON, DC, 1985).

improvements of jet engines performance were obtained, contributing to successive decreases in operational costs. It was in this context that Embraer decided to revise its strategy for the use of jet engines, through the development of the ERJ-145 model. This strategy was also shared by Canadair, which would be converted in Bombardier later[6]. The same innovation strategy was followed by other manufactures in the segment, although only Embraer and the Canadian Bombardier obtained success in the efforts to integrate several systems, subsystems and components to produce regional aircraft based on jet propulsion. The regional jet aircraft models that succeeded from the 90's had two engines in the fuselage rear, reproducing the Caravelle (1959-73) lay-out, the first model to adopt this configuration[7].

Competition in the Regional Aircraft Industry

The main models currently competing in the international market of regional jets are produced by Embraer and Bombardier. However, some model produced by Embraer (E-Jet 190 and 195) also competes with a range of Boeing (717-200 and 737-600) and Airbus (A 318) models. The first models introduced in this segment (CRJ-100) have been traded by Bombardier since 1992. The structural problems faced by the international air market since the middle of the 80's, combined with the economic crisis and the exhaustion of public funds that occurred locally, resulted in the decision took by Brazilian government to privatize Embraer in 1994. This process postponed the release of the first Brazilian regional jet (ERJ-145), which occurred only in 1996.

Later on, the two regional aircraft manufacturers released other models, consolidating the ERJ Family 145/135/140 (produced by Embraer) and the CRJ Family 100/200/440 (produced by Bombardier). Although it started after Bombardier, Embraer was able to keep up with it, encouraging the judiciary process opened by the Canadian government at the World Trade Organization (WTO) against loan mechanisms that was offered by the Brazilian government to support Embraer activities. Then, it was proved that the Canadian government used the same instruments to support its local industry abroad. Although this paper does not intend to discuss the normative issues related to antitrust policies in the aircraft industry, which tend to privilege the mechanisms of price competition, it could be suggested that the focus might be reoriented to investigate how the evolution of Embraer market share could be correlated to the analysis of its innovation strategies, implemented according to the stimulus generated by the dynamics of the product life cycle. In fact, when Embraer launched the 145 model, it was competing in the first

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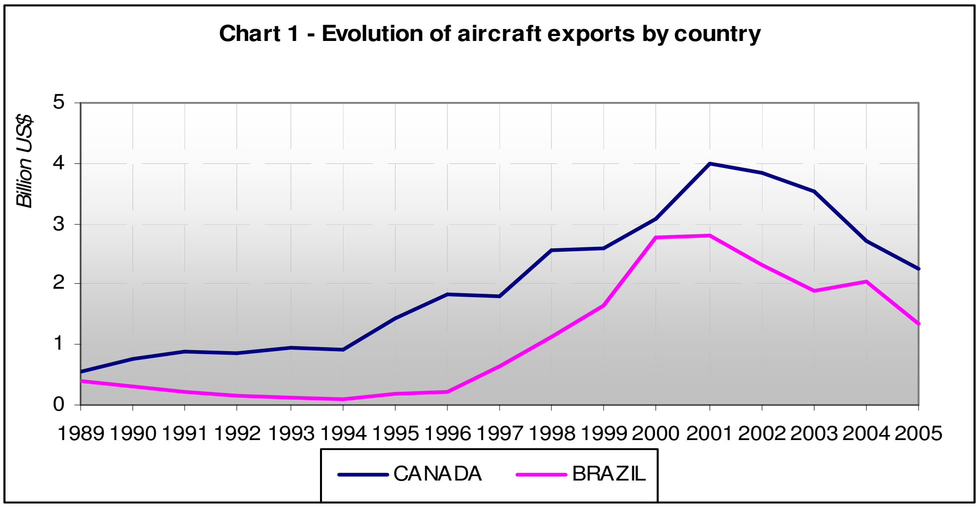
[6] Bombardier was created in the end of the 1980's, trying to react to a recessive scenario of the aeronautic market, which, partly, was explained by the significant changes concerning the role (economic and political) of military sectors all over the world, due to the end of Cold War and also, due to the resistance of some manufacturers to review their strategies towards new projects and loan acquisitions. These same events contributed to the privatization of Embraer in 1994.

[7] Other models developed later, such as the DC-9 (1965-82), MD-80 (1979-99) and the Fokkers 28 e 100 (1986-97), have also established the same engine disposition; however the transport capacity was higher than 50 seats.

phase of the product life cycle, in which prevails a concurrence predominantly based on product differentiation, a tendency that was almost ignored by supranational authorities involved with the regulation of concurrence. Chart 1 shows the behavior of Brazilian and Canadian exports, involving regional aircraft jets with a configuration based on a range between thirty to sixty seats[8]. In this chart, it is evident that the growth phase of the product life cycle has started from the middle 90's on[9].



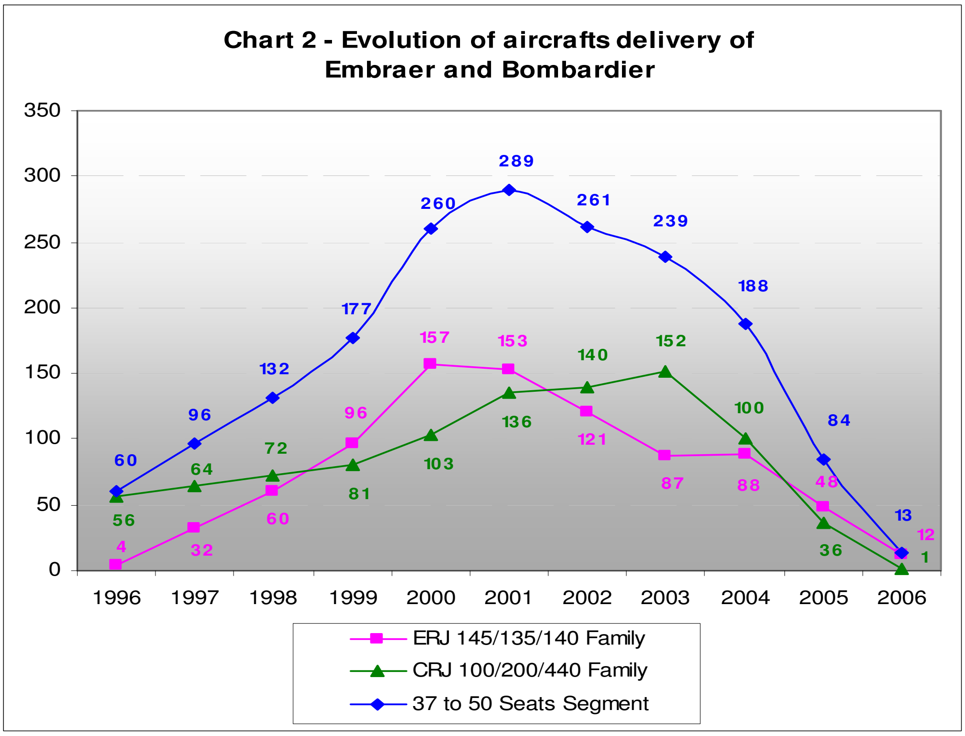
Source: Own elaboration according to data from the *United Nations Commodity Trade Statistics Database (UN comtrade)*, available in: http://comtrade.un.org/. Notes:
(I) These values correspond to world export of each country, on the *792,3 code* of *SITC (Standard International Trade Classification) Review 3* (aircrafts, 2 t < weight < 15 t);
(II) Large executive aircrafts produced in each of the countries are included. In 2000, Embraer released a corporate version of ERJ 135 in the market (which has later changed its name to Legacy). Bombardier is a large manufacturer of executive jets (Challenger, Global 5000 and Learjet) and turboprops (Q 200 and 300 Series); and
Weight ERJ-145 Family (11.4 t to 12.1 t) and weight CRJ-100/200/440 (up to 14.02 t).

The Embraer Regional Jet 145 (with engines located in the rear fuselage) should share 75% of the components and systems with the Brasília model (which has engines located under each wing); however, the 145 model experimented two radical changes that restricted the degree of communality to only 30% in relation to Brasília. Thus, at that moment, this aircraft model began to be seemed as the "state of the art" for the regional aircraft industry. The Canadair Regional Jet 100 was a longer version of the corporate jet Challenger, which had also the basic configuration of two engines in the rear part of the fuselage. It was this configuration that characterized the dominant design of the fifty-seat jets. It is useful to remember that the concept of dominant design (Utterback and Suárez, 1993) derives from the concurrence among economic agents that actively participate in the innovative dynamics through time. However, the regional aircraft industry can take advantage of the "technological tracks" opened by large aircraft manufacturers. These tracks had defined the

[8] The relevant market for regional aircrafts is the international one, which illustrates the tradable character of these goods.
[9] It is important to highlight that Bombardier took advantage of its privileged position in sub-segment of the regional fifty-seat jets market until 1996.

configuration of engines in the rear part of the aircraft body long before they were used in the regional transport.

Based on these models, Embraer and Bombardier developed the remaining models of each family. Embraer decided to adopt the shortening strategy (ERJ-135/140) to the ERJ-145 model, while Bombardier reduced (CRJ-440) and enlarged (CRJ-700/705/900) the structure of the CRJ-100/200 model. Chart 2 illustrates the evolution of aircrafts delivery by Embraer and Bombardier for the 37 to 50 seats segment, which presents a pattern very similar to that proposed by product life cycle[10]. It is also clear that Embraer did not lose the range of opportunities conquered in 1996. Production continued to grow until 2001, diminishing in the five consecutive years. This pattern of evolution resulted in the decrease of the exports, as defined in the subsequent stages of the model of product life cycle. In order to react to this tendency, a joint venture was consolidated between Embraer and Avic II (China Aviation Industry Corporation II) for the manufacturing of aircraft of the ERJ-145 family for the Chinese market.



Source: Own elaboration, through consultancy to the annual reports of Embraer and Bombardier.

The strategy based on the increase of aircraft bodies used in the regional segment was also adopted by Embraer from 1998 on, with the development of the E-Jet 170/190 (E-170/175/190/195)

[10] At that time (1999), Fairchild-Dornier released the 328 Jet (30 seats) model, with a basic configuration quite different from that of the Embraer and Bombardier models - that is, an engine under each wing, arranged above the body structure. Eighty three models were produced until 2002. The 428 Jet (44 seats) model was also part of the 328 Jet family; however, it was never manufactured. Beforehand, in 1993, BAe Systems Regional Aircraft released the Avro (70 to 100 seats) model, which incorporate two engines under each lifted wing. One hundred sixty six models were produced until 2002. Nevertheless, the basic configuration that prevailed for the fifty-seat segment was the models with two engines in the aircraft's tail (Bragança, 2007).

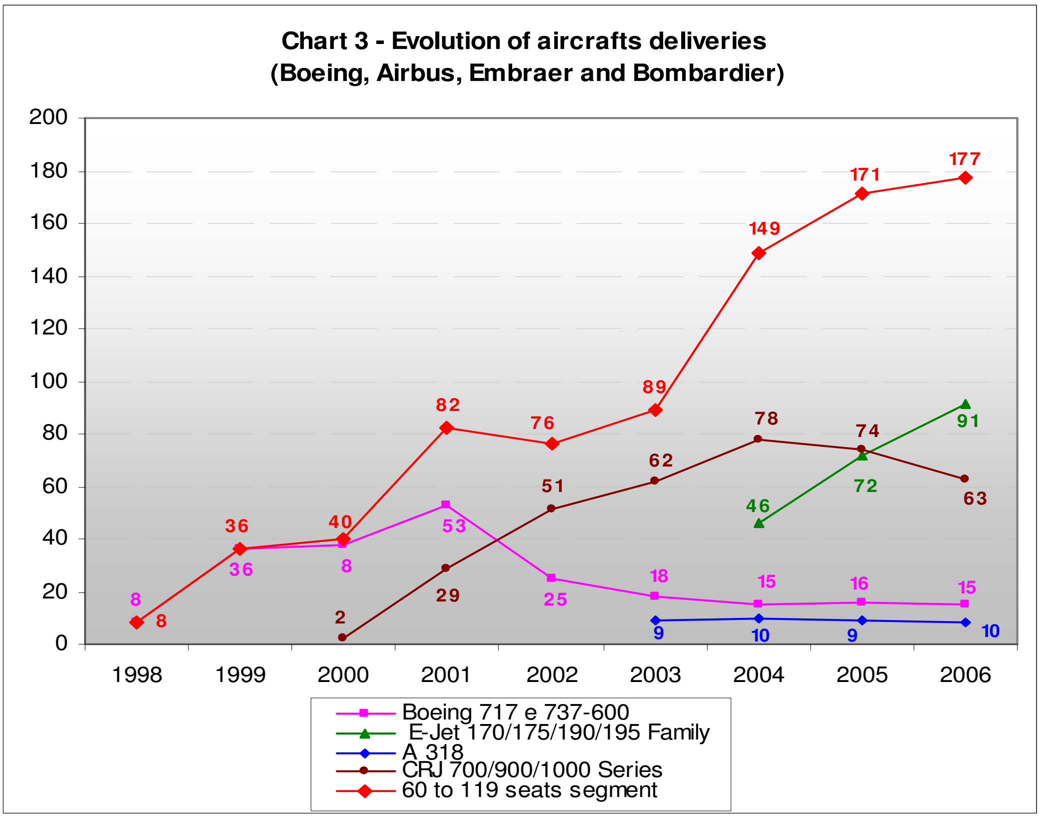
Family, which was adapted to the requirements of the segment between 70 and 122 seats. Starting from the state of art of regional jets, the conception of the models was accelerated through a risk partnership with a larger number of the main suppliers, who began to develop several systems, subsystems and components of the models together with Embraer. This evolution represented a relevant change when compared the partnership previously established to the development of the ERJ-145, in which Embraer provided detailed technical specifications that might be performed by partners and vendors[11].

On the same occasion, the large manufacturers of aircraft structures also identified the presence of a gap that could be explored; however, they started from existing projects, adjusting them in order to the requirements of the new niche. Thus, Boeing adapted the structure of to the MD-80, previously produced by MacDonnell Douglas, re-naming it Boeing 717. It had also released the Boeing 737-600 based on the same principles. Airbus had opted to a reduction of the structure of the A-319 model, calling it A-318. These models have the same basic configuration, with one engine under low wings, consolidated by Boeing 737 in the 60's, a general pattern that had oriented the further growth of the aeronautic industry. But the models manufactured by Bombardier (CRJ-700/705/900/1000) kept the same configuration of the first regional jet (CRJ-100/200), that is, two engines in the rear part of the fuselage. Analyzing these options according to the theoretical concept of dominant design, it could be noted that Embraer, although engaged into an apparently more uncertain path when compared with Bombardier, was benefited from the technological trajectory exploited by large aircraft manufacturers, becoming capable of developing a product in accordance with the state of art.

From the release of the E-Jet 170/190 family on, Embraer surpassed Bombardier, controlling a market share that hadn't been reached in the regional jets market by its contender. Reacting to a movement of progressive exhaustion of the life cycle of the fifty-seat segment, which was reflected in the fall of the export rate since 2001, it began to exploit the growth phase of a new segment from 2004 on, when the first deliveries of 170/190 Family jets came to the market. The growth of the new segment is highlighted by Chart 3, through the evolution of aircraft deliveries that currently compete with the 170/190 Family models (comprehending the segment between 60 and 119 seats). The customer orders of Embraer for this segment added up to 426 models on September 2007, in contrast with the 157 orders of Bombardier and the 53 orders of Airbus. On the same occasion, the customer orders of Boeing for the 717-200 and 737-600 models was null. The last Boeing 717-200

[11] The tendency to reduce the number of vendors and to strength the partnership with key suppliers was started in the 90's, as a response to the new institutional context, which reduced the role of governments in the aeronautic industry, especially in the financing of new projects. Embraer, which comprised 500 vendors in the production of Brasília in the 80's, counted on only four risk partners and 350 vendors in the ERJ-145 project in the 90's. The development and production of the E-Jet 170/190 family was aided by 22 vendors and 16 risk partners. It is worth to emphasize that Embraer remains the ultimate responsible for the project, detaining decisions, definitions and tasks of higher aggregated value.

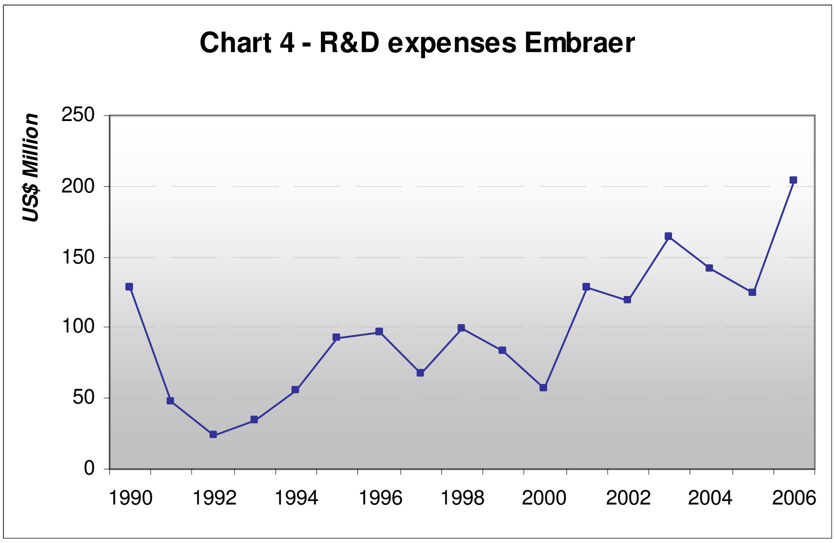
model was delivered on May 2006. In spite of the model 737-600 program is still open, no delivery of this model has occurred since August 2005.



Source: Own elaboration, through consultancy to the annual reports of the enterprises.

To verify the consistency to the strategies implemented by Embraer and Bombardier, an analysis of the R&D expenses carried by those companies seems particularly useful. The Embraer R&D expenses, described on Chart 4, illustrate its efforts to the development of the 145 and E-Jet 170/190 Family. It also demonstrates that the development activities of the first family began at the time Embraer was still a public company. The evolution of R&D expenses after 1998 shows, mostly, the development costs of the E-Jet 170/190 Family[12] . According to Ganem (2006), the overall development cost of the E-Jet family was around US$ 850 million.

[12] From the end of the 90 decade on, Embraer started the development of the military version of the ERJ 145 model (the EMB 145 AEW&C), of the Super Tucano (ALX) and the executive version of the ERJ 135 (legacy) model. It began the development of jet executive models in *Very Light* (Phenom 100) and *Light* (Phenom 300) categories from May 2005 on. In 2006, an executive version of Embraer 190 (Lineage 1000) executive jet of the *ultra-large* category was released. The customer orders for Phenom 100 and 300 recorded over 460 unities in the second quarter of 2007. The first deliveries are programmed to 2008.

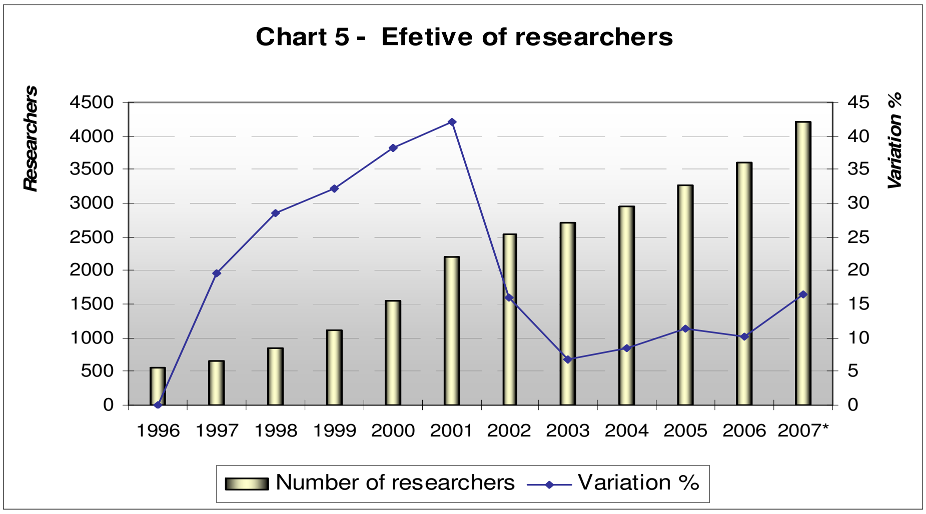


Source: Own elaboration, from Bernardes (2001) between 1990 and 1997 and Embraer.
Note: Values from 1998 were converted to US$, according to the average annual rate.

Bombardier has spent around US$ 65.20 millions in R&D in the aeronautic activities between 2002 and 2006. In earlier years, its annual reports did not distinguish among the values associated with different activities performed by the corporate group. However, even with the analysis of R&D expenses in a consolidated manner[13], it presented an average R&D expenses between 1995 and 2001 of over US$ 90 millions. Considering that Embraer has spent around US$ 90 millions, in average, on the same period and that, for the period between 2002 and 2006, it has spent around US$ 150 millions, we can conclude that Bombardier has engaged into a less aggressive innovation strategy concerning R&D activities, at least in the period comprising 1995-2006.

The Embraer's attempt to sustain a posture marked by the offensive character of the technological strategy can also be seen in the increase of the number of researchers involved in engineering and R&D activities. Chart 5 highlights the evolution of the quantity of workers that take part in those activities. That number has presented growing rates every year, from 1996 to 2001, reflecting Embraer efforts to develop the E-Jet 170/190 Family.

[13] Bombardier currently manufactures trains, *(transportation)* and aircrafts *(aerospace)*. But, it has already manufactured ATVs and snowmobiles *(recreational products)*, ceasing to produce them in December, 2003.



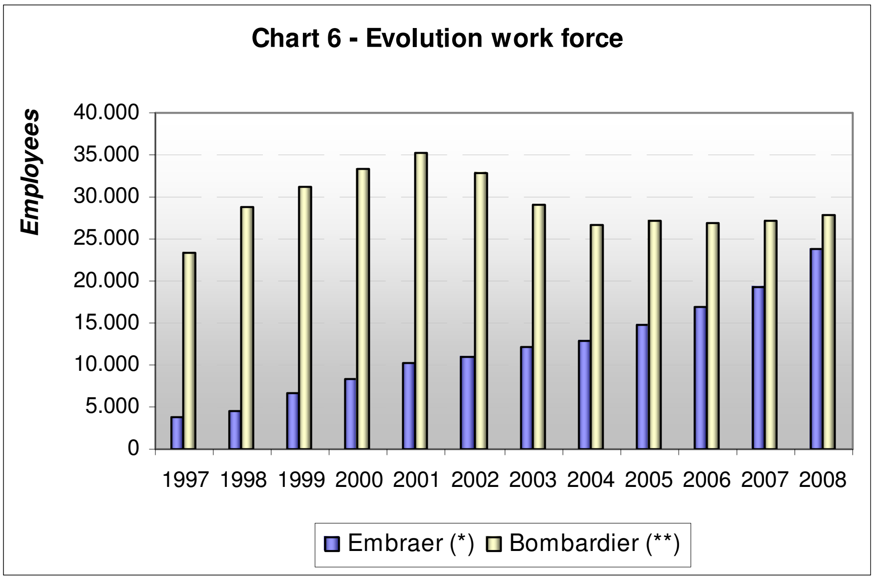
Source: Own elaboration, through consultancy to the annual reports of Embraer. Note: (*) June.

The built of competences that occurred simultaneously with the deepening of R&D expenses has also relevant implications to Embraer organizational structure. Bernardes (2000) states that, since 1998, Embraer created a "market intelligence"[14] department, through which the company aims to meet the clients' needs generated by their air transport activities. This department amplifies the possibilities of innovation and learning interactions with potential clients. Embraer has also internalized a prospective methodology about market awareness and the potential needs for airline companies. This methodology permits to anticipate the evolution of market trends by quantifying global demand for regional aircrafts. The analysis is based on the application of *top down* techniques, which consists in evaluating elements such as: 1) general characteristics of air fleets, 2) operational aircrafts, 3) sales evolution, 4) *backlog* (delivery requests), 5) relation between sales and deliveries. Another complementary methodology is based on a *bottom-up* technique, involving the establishment of a direct contact with airline companies, through which it is possible to obtain information about the occupation rates in the routes they operate and about aircraft model well adapted to their needs.

The strengthening of those activities inside Embraer organizational structure has contributed to the increase of its competitiveness and to progressive reduction of Bombardier's market share. As a consequence, Bombardier has reduced its workers, whereas Embraer increased the number of workers in its plants. Chart 6 compares the evolution of the labor force in Embraer and Bombardier to the period between 1997 and 2008. It is important to emphasize that the growth of Embraer's employees has occurred simultaneously to a process of huge increase of the investments in the productive process, involving, for example: (1) the replacement of electrostatics method of aircraft

[14] It was from the second semester of 1998 on that Embraer, after analysing the world market trends in air transport, identified the need for models in the segment of 70 to 110 passengers, due to a range that is not reached by aircraft manufacturers. This range was defined, on one hand, by large aircrafts that served end-to-end routes, with an intense aircraft traffic with 120 *plus* places and, on the other hand, by a regional segment of a little more than 50 seats. On that occasion, it was noted that one third of the operating aircrafts of 61 to 120 seats had reached its limit concerning its service life (more than 20 years of use).

painting by a semi-automated process; (2) the replacement of rack inspection system with conventional theodolite that demanded four operators by a laser measurement system with one operator, allowing the decrease of tools manufacturing cycle in about 20%; (3) the replacement of the manual cut of previously impregnated plates by the automatic cut, which enabled a reduction of about 3,000 Hh/month; (4) the automated mounting of aircraft wings; (5) the installation of a high-precision machining equipment based on 5 high speed axis; (6) the installation of a virtual reality center, in February, 2002, enabling the use of a digital "mock-up". According to Embraer, these investments have permitted a reduction of the aircraft production cycle from 6,2 months in 1999 to 4,9 months in the second semester of 2000. In 2007, the ERJ-145 production cycle took 3,1 months and the Embraer 170 production cycle took 4 months.



Source: Own elaboration, through consultancy to the companies' reports.
Note: January (*) 1st and (**) 31st.

Table 1 highlights some technical information about the main models that compete with the aircrafts manufactured by Embraer. Presently, Embraer holds the regional aircraft market leadership for commercial aviation. Although the chart includes some large manufacturers' (Boeing and Airbus) - because of the new range (70 to 122 seats) attended by the Brazilian company - Embraer's main concurrent remains the Canadian Bombardier. With the first sales of the ERJ-145 Family, Embraer started to recover the investments made in this line, having aggregated 915 orders until the third quarter of 2007. The release of the new E-Jet 170/190 Family has contributed to surpass Bombardier's position in the regional aircraft industry. The backlog of Bombardier totalized 538 jets of the CRJ-700/705/900/1000 models, while Embraer's backlog aggregated 718 models.

Table 1 – Basic features of regional jets

	Models	Engines nº	Engines Localization	nº of seats	Reach (Km)	Cruising speed (Km/h)	Year of first delivery	Total of aircrafts delivered	Total of aircrafts in backlog	Total of aircrafts orders
EMBRAER	ERJ 145	2	C	50	2.871-3.704	833	1996	682	51	733
	ERJ 140	2	C	44	3.056	833	2001	74	0	74
	ERJ 135	2	C	37	3.241	833	1999	108	0	108
	E 170	2	A	70-80	3.890	870	2004	137	26	163
	E 175	2	A	78-88	3.704	870	2005	46	60	106
	E 190	2	A	98-114	4.445	870	2005	99	292	391
	E 195	2	A	108-122	4.074	870	2006	10	48	58
							Total	**1.156**	**477**	**1.633**
BOMBARDIER	CRJ 100	2	C	50	1.815	786	1992	226	0	226
	CRJ 200	2	C	50	2.491- 3.148	786-860	1995	709	0	709
	CRJ 440	2	C	40-44	2.491- 3.148	786-860	2002	86	0	86
	CRJ 700	2	C	about 78	2.655- 3.704	828-875	2001	255	11	266
	CRJ 705	2	C	about 75	3.139- 3.730	828-881	2006	15	0	15
	CRJ 900	2	C	about 90	2.500- 3.385	828-881	2003	111	108	219
	CRJ 1000	2	C	86 -100	2.761- 3.131	827-870	-	0	38	38
							Total	**1.402**	**157**	**1.559**
BOEING	B 717-200	2	C	106	2.645- 3.815	818	1999	156	0	156
	B 737-600	2	A	110 -132	2.480 -5.648	834	1998	69	0	69
							Total	**225**	**0**	**225**
AIRBUS	A 318	2	A	107	2.700- 5.950	870	2003	47	53	100
							Total	**47**	**53**	**100**

Source: Own elaboration, through consultancy to the companies sites of Embraer; Bombardier; Airbus and Boeing, in the third quarter of 2007. Note: (*) C ≡ Tail and A ≡ Under the wings.

Conclusive remarks

The competitive dynamics in the aircraft industry presents a cyclical pattern that might be understood through the analytical framework provided by the product life cycle theory. In that industry, each cycle is commanded by a dominant design associated with the capacity of passengers´ transport. Aircraft builders tend to implement offensive-defensive technological strategies to define this design and to appropriate the profits provided by the technological leadership. The enterprises that take the lead of the process can adapt the characteristics of the models according to the needs of the airline companies. In the regional aircraft industry, the heterogeneity of the airline companies reinforces the importance of the competences accumulated by aircraft builders in order to generate adjustments that strengthen their competitive position in the market. Starting from the moment in which the regional aircraft builder defines some key aspects of the design – particularly those related to the position of wings and engines in the airplane body and to number of seats – a cumulative trajectory based on lock-in effects tends to be generated. At the same time, the competitive dynamics generated by the progressive diffusion of that design tends to increase the level of market concentration, with the aircraft builders not adapted to the requirements of the dominant design being punished through the reduction of their market shares. At the same time, a general pattern of subcontracting relations tend to be established with key suppliers of the aircraft industry, reinforcing the cumulative evolution along the trajectory defined by the dominant design.

In this context, the definition of technological strategies must be synchronized according to the phases of product life cycle, in order to exploit some opportunity windows opened by the evolution of the market. In this sense, market-monitoring competences tend to be a critical aspect that strengthens the competitiveness of regional aircraft builders. The strengthening of these competences might be compatible not only with strictly offensive strategies but also with defensive strategies that follow the technological leaders and are based on efforts specifically oriented to differentiate the product according to market needs. This pattern makes extremely difficult the previous identification of the strategy that tends to be broadly adopted by regional aircraft builders.

The analysis of the regional aircraft industry developed in the previous sections emphasized the capacity of Embraer to construct competences and to exploit opportunity windows opened by the evolution not only of the technological trajectory but also of the institutional context in which the industry has operated. In this sense, the understanding of Embraer strategy might be correlated to the co-evolution of stimulus generated by those two dimensions. At the technological level, Embraer strategy seems to be very effective, exploiting the possibilities opened by the progressive consolidation of a dominant design to regional aircraft bodies well adapted to the needs of regional airline companies. At the institutional level, the opportunities opened by the deregulation of regional airline markets – starting from the North-American experience – amplified the competitive gains potentially associated with a product well adapted to the market needs.

When the innovative efforts (including R&D expenses) developed by Embraer are confronted with Bombardier, a mix of offensive and defensive strategies might be observed along time. However, the strengthening of competitive positions has tended to be more correlated to the timing that to a clearly orientation of technological strategies. In fact, Embraer had launched its first family of regional aircraft jets (ERJ –145) at the beginning of the product life cycle, in an uncertain competitive context that tended to reinforce the potential gains generated by product differentiation. The capacity to develop a product better adapted to the market needs resulted in the strengthening of Embraer competitiveness, as well as in the progressive reduction of Bombardier market share. So, the competitive dynamics in the regional aircraft industry has seem to be strongly affected by the capacity to adapt the technological strategies implemented according to the possibilities opened by the progressive consolidation of a dominant design along the product life cycle and by selective mechanisms defined according to market stimulus.

However, the current situation of the industry might be radically transformed according to the forces it faced along time. In this sense, the evolution of the competitive dynamics of the industry might be seem as a product of different stimulus. Considering the proposals of Malerba and Orsenigo (1996), it is possible to identify three critical aspects that might affect this dynamics along time. At the level of "industry dynamics", it might be stressed aspects related to industrial demography, reflecting entry and exit movements of firms, as well as the distribution of firms according to its size and the prevalence of relevant asymmetries among them in terms of technological capabilities.

The recent the movement of new entrants characterized constitutes a key aspect of the "industry dynamics" in the regional aircraft industry. In fact, after the release of the -Jet 170/190 Family by Embraer, another builders have entered in the regional aircraft industry, stimulated by attractive perspectives of market growth, especially with the impressive dynamism of the chinese economy. Among the new entrants that have come to the industry, we can mention:

(1) Avic I (China Aviation Industry Corporation I) has initiated the development of the ARJ-21(Advance Regional Jet of the XXI Century) Family in 2002, with a configuration very similar to the ERJ-145 Family (low wings with two engines in the back fuselage). Chinese aircrafts are foreseen to be launched in 2010 with two basic configurations: (i) ARJ 21-700 model, which can transport between 78-90 passengers, with an autonomy between 2.225 and 3.700 Km (to this model, the package has already reached 71 orders); (ii) ARJ 21-900 model, which can transport between 98-105 passengers, with an autonomy between 2.225 and 3.334. At the same time, Embraer has consolidated a joint venture with Harbin Aircraft

Industry Group and Hafei Aviation Industry; two enterprises controlled by Avic II, located in Harbin, the capital of the province of Heilogjiang. With 51% of its share, Embraer assumes the control of the joint venture, with the purpose of producing models of the ERJ-145 Family to the Chinese market, which is supposed to reach an annual growth around 7% for the next 20 years. The package orders of the new company became expressive only in 2006, when it was announced the selling of 50 ERJ-145 jets to HNA group, the fourth largest airline company in China. This group has also acquired 50 jets of Embraer 190, achieving an amount of orders around US$ 2,7 billions.

(2) The Russian producer of military aircraft Sukhoi has also entered the market of regional aircraft jets, with its Superjet 100 model, produced in versions of 75, 95 and 110 seats. The family was launched during the Paris Aeronautic Exhibition in 2007, with ten units being sold and another 15 being promised as orders to the ItAli, an Italian regional airline company. These models have an attractive price, being sold with a price around US$ 25 millions (compared with a cost of around US$ 29-36,5 million of E-Jet).

(3) The Japanese Mitsubishi is currently developing air jets to the regional market - the MRJ (Mitsubishi Regional Jet) 70 and 90 – based on engines produced by GE, Pratt & Whitney and Rolls Royce. The first model will have a capacity to transport between 70-80 passengers, and the second around 86-96 passengers. These models are expected to have an autonomy between 1.610 and 3.910 Km, being based on a lighter structure provided by composite materials. The company intends to launch these models around 2012.

At the level of the "structural dynamics", it is observed that the innovations incorporated in aircraft structure remains a "driving forces" that define how the industrial structure changes along time. In this sense, the new models that are being developed by Russian and Japanese builders maintain the basic configuration introduced in the regional aircraft jets through the E-Jet 170/190 Family, with motors located under the wings. This configuration has characterized the dominant design of large aircraft jets since the introduction of the Boeing 737, being reproduced and adapted to the new regional segment – based on structures with 70-122 seats - inaugurated by Embraer. The innovative dynamics remains very intense in the regional aircraft industry, being strongly based on the incorporation of electronic components, the introduction of new materials, the strengthening of cooperative links with key suppliers and the adaptation of lay out of the aircraft body according to the needs of the customers. However, the progressive expansion of the regional aircraft builders to a segment based on large bodies might be followed by the increase of competitive risks. In fact, when those builders amplify their target to the segment of regional jets with a capacity above 120 seats, they tend to face the direct concurrence of the biggest aircraft builders, concurring in the same segment of aircraft constructed by Boeing (717-200 e 737-600) and Airbus (A 318). Finally, at the level of the “structural evolution” of the industry, there are some evidences that the progressive maturation of the aircraft structures along the product life cycle might be supplanted by the introduction of innovation – not necessarily radical innovations – with the capacity of generating a new cycle before the complete exhaustion of the previous. The possibility of defining a new configuration for regional aircraft bodies – based on a range between 70-122 seats – might also be correlated to this trend, despite the risks it involves. On the other hand, these risks may be partially compensated by the huge increase that has foreseen to the regional airline markets, particularly associated with the perspective of a sustainable growth of the BRIC countries, where the current demand of these markets is still limited.

Finally, the recent evolution of the regional aircraft industry might be used to illustrate the importance of institutional factor that have affected the technological trajectory and the competitive dynamics in this industry. Among these factors, particular relevance may by be attributed to the stimulus and restrictions provided by the industrial policy and by regulatory issues. At the level of the industrial policy, aircraft industry remains a strategic focus not only because of its technological dynamism and of the broader impact it generates over other industrial sectors, but also because of its geopolitical importance. In fact, the availability of a well-structured local aircraft industry seems particularly relevant to large territory countries, such as the BRIC countries, to permit a reduction of the spatial disparities generated by the process of socio-economic development. At the same time, the recent experience of the regional aircraft industry points out many examples about how the set of instruments of economic policy – especially at the level of industrial and commercial policies - of might be mobilized to protect the interests of local aircraft builders. As an example, we can mention the pressures implemented since 1996 by the Canadian government at the level of the World Trade Organization (WTO) questioning the mechanisms offered by the Brazilian government to support the financing of Embraer sales. The paradox implicit in these pressures is that the Canadian government also has given an important support to Bombardier activities through the *Canada Account* program, administrated by the Canadian official credit agency that supports local exporters, the *Export Development Corporation.* All these events may illustrate the importance of correlating the dynamic aspects of the concurrence that prevails in the regional aircraft industry with institutional factors, in order to explain how the industrial structure of the segment evolves along time. At the theoretical level, these aspects emphasize the importance of articulating the international trade theory with regulatory issues proposed by the antitrust policies, in order to capture the impacts of innovative dynamics to the concurrence. In fact, the institutional determinants that affect the concurrence in the regional aircraft segments do not might be exclusively associated with a static analysis of the concurrence, but also with a competitive dynamics systematically redesigned by the innovations introduced by aircraft builders.

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