IV ENEI
Encontro Nacional de Economia Industrial e Inovação
Inovação, Produtividade e os Desafios do Crescimento
10 a 12 de setembro de 2019
Campinas, São Paulo

Brazilian Aeronautical Industry: An Approach to Public Policies

Marcos José Barbieri Ferreira e Thiago Caliari[1]

Área 1. Indústria e Competitividade

1.1. Dinâmicas industriais setoriais e dos sistemas de produção

Abstract: This paper aims to present the evolution of the Brazilian aeronautical industry focusing on public policies. We analyse it under theoretical approaches of Innovation Systems and Global Value Chains considering that a consolidated arrangement in national boundaries is useful to improve national firms, in order to compete at the international level. The government's role on the aeronautical industry is considered as a mission-oriented policy. As main conclusions, we highlight that public policies shift as new results are achieved and new goals are being established, in line with a mission-oriented innovation policy. Hence, the need for evaluation and adjustment over time would be seen as a more general lesson from this paper, and the role of government intervention emerges as a particular strategy for each nation-state.

Keywords: Global Value Chains; Innovation Systems; aeronautical industry; mission-oriented policy; Brazil.

***Resumo*:** Este artigo tem como objetivo apresentar a evolução da indústria aeronáutica brasileira com foco nas políticas públicas. Analisamos isso sob as abordagens teóricas dos Sistemas de Inovação e das Cadeias Globais de Valor, considerando que um arranjo consolidado nas fronteiras nacionais é útil para aprimorar as empresas nacionais, a fim de que compitam em nível internacional. O papel do governo na indústria aeronáutica é considerado como uma política orientada por missões. Como principais conclusões, destacamos que as políticas públicas mudam à medida que novos resultados são alcançados e novas metas vão sendo estabelecidas, em linha com uma política de inovação orientada por missões. Assim, a necessidade de avaliação e ajuste ao longo do tempo seria vista como a contribuição mais geral deste artigo, e o papel da intervenção governamental surge como uma estratégia particular de cada Estado-nação.

***Palavras-chaves*:** Cadeias Globais de Valor; Sistemas de Inovação; indústria aeronáutica; política orientada por missões; Brasil.

JEL: L52; L62; O38; O31

[1] Respectivamente, professores da Faculdade de Ciências Aplicadas da Unicamp (FCA/Unicamp) e do Instituto Tecnológico de Aeronáutica (ITA). Emails: marcosbarbieriferreira@gmail.com e caliari@ita.br.

Introduction

Growing collaboration among enterprises is seen on the global network as a way to respond to market pressures and improvement on competitive capabilities in a globalized environment (GEREFFI, 2014; MONROY; RAMÓ; ARTO, 2010). In some industries with global demand this pressure is more urgent; this is the case for the aeronautical industrial complex. Global partnerships are being increased by civil aircraft original equipment manufacturers (OEM) to reduce costs and uncertainties, besides taking advantage of the technological expertise of specialized suppliers, concentrating effort on their competence in design, assembling and marketing aircraft (NIOSI; ZHEGU, 2005). This behaviour reflects the relevance of a global network for production and innovation based in Global Value Chains (GVC), under which the role of global lead firms is the main determinant for the upgrading of supplier firms.

Despite that, centripetal forces seem to be important to explain aeronautical clusters globally; there are 47 aeronautical clusters in Europe nowadays (EACP, 2018), in addition to 12 major clusters in North America (NIOSI; ZHEGU, 2005). In emerging markets, government strategies to foster their aeronautical clusters can be seen (CHANGXI, 2016; GORDON, 2008; KETELS *et al.*, 2015; LEE; YOON, 2015; STURGEON *et al.*, 2013; FERREIRA, 2009), given the industry impact on employment, productivity and technological spillovers. Altogether, aeronautical industry tends to maintain strict links with national governments due to issues related to sovereignty and strategies to foster the industrial and technological complex (given its high technology density and many different technologies embedded in the final product) (HAYWARD, 1994).

This relationship is closely related to mission-oriented policies (MAZZUCATO, 2017), since it is a crucial asset for countries. A mission-oriented policy is related to specific goals, exactly the case of the aeronautical sector, where national sovereignty combined with a high-technology-based sector makes the role of the government so important.

In this work, we aim to study the Brazilian aeronautical industry through those approaches. It is considered the relevance of governance of lead firms in GVC perspective, but we believe a joint look considering Innovation Systems (as mission-oriented policy specifically) and GVC may highlight an important feature for successful national firms in technology-based sectors: a consolidated arrangement in national boundaries are useful to improve national firms, in order to compete at the international level; improving competitiveness of national firms at GVCs implies on designing innovation policies focused on developing strong innovation systems.

The research question raised here is: what was (and what is) the government's role in the evolution of the Brazilian aeronautical industry? Our findings highlight that public policies shift as new results are achieved and new goals are being established, in line with a mission-oriented innovation policy. Hence, the need for evaluation and adjustment over time would be seen as a more general lesson from this paper, and the role of government intervention emerges as a particular strategy for each nation-state.

The remainder of this paper is divided into four sections. In section 2, a theoretical framework is presented. After that, a brief summary of the evolution of the aeronautical industry is highlighted as a way to facilitate the understanding of public policies, which will be the focus of section 4. The discussion and conclusions section will bring the paper to a close.

2. A theoretical framework to public policies in the Aeronautical Industry

2.1. Innovation Systems and Global Value Chains

Innovation is rarely dependent on a single agent, rather, it is frequently a result of a complex network, not only made of different domestic organizations and institutions, but also of their global insertion (BINZ; TRUFFER; COENEN, 2014; COOKE, 2001; PEPPARD; RYLANDER, 2006). Therefore, a consistent view on innovation integrates both national and international perspectives, regarding the capacity of organizations (mainly firms) to be part of productive activities.

Integrating the Innovation Systems (IS) approach (FREEMAN, 1992) to Global Value Chains (GVC) (PORTER, 2001) would be useful to understand the evolution of relatively more technologyintensive sectors, a task that has been brought about by the recent economic literature (GEREFFI, 2014; PIETROBELLI; RABELLOTTI, 2009; SZAPIRO *et al.*, 2016).

At the national sphere, the Innovation Systems perspective (FREEMAN, 1992) stresses that the flows of knowledge among organizations in an economy is a key factor for an innovative process. This approach is interesting because it involves analysis in more varied forms of space and sectors. The basic initial considerations have been delineated within national boundaries (FREEMAN, 1992), but other approaches have proposed a more regional view (Regional Innovation System) (COOKE, 1992; FLORIDA, 1995) or a sectoral view (Sectoral Innovation System) (MALERBA, 2002).

According to the GVC perspective, a value chain is seen as the full range of activities required to finish a product, which includes activities such as design, production, marketing, distribution, support and after-sales services to the final consumer. When these activities are divided among different enterprises located in different countries, we are talking about Global Value Chain (PIETROBELLI; RABELLOTTI, 2009, 2011). When considering a specific GVC, its layers can be located at any part of the world, and firms interact globally to offer the product as competitively as possible. The aeronautical sector is an example of this competitive arrangement (FERREIRA, 2009; MAZZUCATO; ROBINSON, 2017), but the same conduct can be seen in the mobile phone sector (PEPPARD; RYLANDER, 2006; STEINBOCK, 2003) or integrated circuits sector (LEE.; VON TUNZELMANN, 2005), just to name a few.

The challenge on this theoretical approximation relies upon a governance criterium: in the IS perspective, a well-stablished strategy is pursued by local/national governments to support improvement on firms' (and other agents') capacitation on innovative and market competitiveness features (namely upgrading process); in the GVC approach, the knowledge required for upgrading flows within value chains is given under the concept of 'governance', under which the literature explains the role of global lead firms in determining the upgrading opportunities of local producers (SZAPIRO *et al.*, 2016). A different government role is proposed in the GVC perspective, as pointed out by Gereffi (2014, p.437):

> *The rise of GVCs occurred in a period of falling trade barriers, the emergence of the WTO, and the policy prescriptions associated with the 'Washington Consensus'—i.e., that governments had only to provide a strong set of 'horizontal' policies (such as education, infrastructure, and macroeconomic stability) and be open to trade in order to succeed.*

Despite that, a crescent number of academic studies are being formulated to meet these approaches, since industrial policies are increasingly being used by countries/regions nowadays (GEREFFI, 2014). The idea is that firms need strong national basis to support their own technological development, as well as they need to consider cooperative/competitive agents globally, and the hierarchy derived from GVCs is not able to warrant that, mainly in less developed countries (GEREFFI, 1999, 2014; SZAPIRO *et al.*, 2016).

We believe a joint look from both the IS and the GVC perspectives may highlight an important feature for successful national firms in technology-based sectors: innovation development within national boundaries are fundamental to improve national firms, in order to compete at the global level. As a result, improving competitiveness of national firms at GVCs implies on designing innovation policies focused on developing strong national (regional/sectoral) innovation systems.

2.2. Government's role

With respect to the IS approach, some key principles can be noted, regarding agents and interactions. First, firms are usually the agents that introduce innovations to the markets. Second, universities and research institutes are usually the agents responsible for producing scientific knowledge,[2] as well as for providing human resources training. Last, but not least, the public sector has an important role in its most varied forms of action.

Despite sharply conflicting opinions on the government's proper role in the economy, some of the most relevant innovations have been reinforced by government involvement. Cases of technologies embedded in equipment (MAZZUCATO, 2015), the development and creation of enterprises in developing

[2] Mainly if we are considering science-based sectors as defined by Pavitt (1984).

countries (KIM, 1997; KIM; NELSON, 2005), subsidies for R&D to foster the innovative capacity of firms (ARAÚJ*O et a*l., 2012; AVELLAR, 2009; BOEING, 2016; GUAN; YAM, 2015), and public procurement for innovation (PPI) (EDQUIST, C *et al.*, 2015; MIRANDA, 2008; MOWERY; ROSENBERG, 2005) are frequent when studying innovation and production. Thus, government action is essential, whether it involves defining boundaries to competition (regulation) or subsidizing firms in international contexts (commercial issues). Such procedures have been highly prevalent in observed historical experience, mainly when public action meant to foster industrial sectors with economies of scale and scope, technological spillovers or national strategic motives.

In this sense, a Mission-Oriented Innovation Policy (MOIP) approach is a relevant strategy for studying the government's role (MAZZUCATO, 2017; MAZZUCATO; PENA, 2016). As pointed out by Mazzucato and Pena (2016, p.6), we describe MOIPs as "(…) systemic public policies that draw on frontier knowledge to attain specific goals or big Science deployed to meet big problems". Mission-Oriented Innovation Policies are related to specific goals, exactly the case of aeronautical sector, where national sovereignty combined with the vision of a sector with high technological density and technological linkage makes government's role so important. However, the intensity and role of government action on IS, based on MOIPs, changes over time. The role of the public sector 'will be particularly important in the early, capital-intensive high-risk areas that the private sector tends to shy away from. But more generally, there is a catalytic role for government in creating and shaping markets through dynamic public private partnerships' (MAZZUCATO; PENA, 2016, p.6). It is expected to find distinct formats of public policies in a specific sector where a mission-oriented innovation policy is practiced, if we study the evolution of the aeronautical sector. As considered by researchers, a government should monitor the needs of the innovation system to provide conditions for firms – and other agents – to be able to compete in established GVCs.

For this task, the proposition of Edquist *et al* (2015) regarding a 'holistic innovation policy' may be considered as a good tool to capture government inclusion. A 'holistic innovation policy' can be defined as a policy that integrates all public actions that influence or may influence innovation processes (EDQUIST et al., 2015), and assumes that public interventions should be better coordinated to improve results from public policies. In Table 1 the main activities practiced by a government to improve an innovation system are presented, following what is proposed in Edquist *et al* (2015).

Table 1 – Key Activities in Innovation Systems

I. Provision of knowledge inputs to the innovation process
1. Provision of R&D results/creation of new knowledge
2. Competence building
II. Demand-side activities
3. Public procurement for innovation
4. New product quality requirements
III. Provision of constituents
5. Creating and changing organizations needed for new fields of innovation
6. Networking through market and other mechanisms, including interactive learning among different organizations involved in IS
7. Institutions (patent laws, tax laws, environment and safety regulations, R&D investment routines, culture norms)
IV. Support services for innovating firms
8. Incubation activities
9. Financing of innovation, productive and commercial processes
10. Provision of consultancy services relevant for the innovation process (technology transfer, commercial information, legal advice)

Source: Based on Edquist *et al* (2015).

The activities are divided into four categories: (i) providing new supply capabilities, (ii) providing demand, (ii) creating incentives through institutions and norms and (iv) providing support services for innovating firms. For a 'holistic innovation policy', the interaction of public agents around these activities is important to optimize results; the action may be coordinated and integrated, considering links and agents of the innovation system. It has a strategic behaviour, planning the possible effects on the supply chain and demand, applying the necessary corrections for the desired results considering a complex system.

Besides, a 'holistic innovation policy' view is useful to measure effectiveness and relationships, given its strategic nature (which, considering the training acquired in its formulation, still allows rapid responses to trajectory changes). In other words, we expect holistic innovation policies to be broader in their scope, considering all key activities for an innovation system. In addition, thinking about policies for innovation in a systemic way is more congruent with changes in developmental strategies over time, since it allows for a direct understanding of changes public agents' actions or in the interactions with the other agents.

Given that, our argument in this work is that historical evolution of the industrial, scientific and technological structure of the Brazilian Aeronautical Industry should be studied as a mission-oriented policy through a 'holistic innovation policy' tool. We understand that the ability of a mission-oriented policy in training agents of the Brazilian Innovation System improves the competitive trajectory of firms in the aeronautical GVC. In this sense, the table proposed in Edquist *et al* (2015) is helps to capture the government's role over time. It will enable us to verify how the public sector has been changing its intervention, and how this behaviour has shaped the competitive pattern of the aeronautical industry.

In the following sections, we will present innovation/industrial policies in the Aeronautical Innovation System in Brazil in the light of those approaches, assessing results and trajectories of competitiveness.

3. A brief presentation of the Brazilian Aeronautical Industry

In the 1930s, both private and public companies tried to develop viable productive structures for airplanes in Brazil, as part of an effort which was mainly linked to a deliberate strategy for the country's industrialization. However, until the end of the 1960s, almost all Brazilian aircraft companies went bankrupt and were dismantled (BERTAZZO, 2003).

The emergence of Brazil's aeronautical industry is frequently associated with the inception of the Aeronautics Technology Centre (*Centro Tecnológico da Aeronáutica* – CTA) in 1947. Inside its boundaries, CTA structured the Aeronautics Institute of Technology (*Instituto Tecnológico da Aeronáutica* – ITA), an aeronautical engineering school,[3] and the Institute for Research and Development (*Instituto de Pesquisas e Desenvolvimento* – IPD), established in 1950 and 1954, respectively. CTA was founded under a military context, subordinated to the Brazilian Air Force (*Força Aérea Brasileira* – FAB), to provide the human and material resources required for the development of aeronautical technology in Brazil (SARTI; FERREIRA, 2012), in a joint strategy for national sovereignty and consolidation of sectoral knowledge (GARTENKRAUT, 2008). Succinctly, these institutions were important for private companies (mainly formed by ITA alumni) and to establish the largest Brazilian aviation company in 1969, Embraer, a state-owned IPD spin-off enterprise. Embraer began to operate on an industrial scale guaranteed by the initial impulse of public procurements; FAB purchased 80 EMB-110 Bandeirante and contracted the license to assembly 112 light attack MB-326 aircraft from Macchi, an Italian aircraft developer (SILVA, 2008). During its first years of operation, Embraer established a contract with the Brazilian Ministry of Agriculture to design and produce an agricultural aircraft, the so-called Ipanema (EMB-200) – still produced nowadays – and, on a smaller scale, the glider Urupema to FAB.

From the beginning, Embraer and CTA showed a significant synchronicity: the former was specialized in the field of aircraft design and assembly technology and the latter was a provider of scientific and technological support. This strategic option of concentrating efforts in the constitution and strengthening of Embraer allowed the company to build competencies in the main technologies that allowed the design and production of new aircraft, in the late 1970s (SARTI; FERREIRA, 2012). On the other hand, only a few national companies could qualify as specialized suppliers of Embraer, most of them operating at the lowest levels of technological sophistication (BERNARDES, 2000; GOMES, 2012).

During the 1970s and 1980s, Embraer had a commercial advantage in the regional civil aviation market, initially with the EMB-110 Bandeirante and subsequently with the EMB-120 Brasília. This was

[3] The institute was delineated following MIT standards, and the first rector was an MIT professor, Dr. Richard Smith (FORJAZ, 2005; GARTENKRAUT, 2008).

possible thanks to the company's certification of aircraft by European and North American agencies (SILVA, 2008). Moreover, Embraer was the main beneficiary regarding the absorption of technology from military attack aircraft projects, despite its commercial failures (MB-326 in the 1970s and AMX in the 1980s) (CABRAL, 1987; MIRANDA, 2008; FRANCELINO, 2016).

A specific program was set up to AMX program (*Programa de Industrialização Complementar* – PIC) in the 1990s by the federal government, aiming to foster the expansion of Embraer's local supplier chain, since its local supplier base was not well structured. The results, however, were not entirely satisfying: only the firm CELMA and Embraer's own equipment division were able to achieve satisfactory technological capacity, manufacturing turbines and landing gear, respectively (FERREIRA, 2009; FRANCELINO, 2016).

In the 1990s, the industrial complex suffered a setback with the combination of internal and external economic restrictions, directly impacting the leading company and, even more seriously, local suppliers, hastening the extinction of some of those companies. In 1994, Embraer was privatized. It developed a new regional airplane, the ERJ-145. The firm then used a new mode of partnership that would later become the standard throughout the global aviation chain, called 'risk partnerships'. In this model, Embraer's suppliers, almost entirely located in other countries, were jointly responsible for the development of specific parts and shared the risk with the leading company. As the project was successful, venture partner companies became long-term suppliers with exclusive contracts (LIMA, 2005). The success of this model was deepened in the new family of commercial jets (EMB-170/190, later known as E-Jets), establishing the company's leadership in the regional jet sector.

The table below highlights the huge participation of Embraer in the domestic aeronautical industry. The existence of a strong and competitive leading company surrounded by a weak base of local companies is still one of the main characteristics of the Brazilian aeronautical industry. In this sense, the great advance of the Brazilian aeronautical industry is confused with the success of its leading company.

Table 2 – Brazilian Aeronautical Industrial Complex – Recent years

Year	Employees of Embraer in Brazil	Total amount of employees	% of Embraer's employees	Total amount of companies	Average number of employees (except Embraer's)	% of firms with less than 100 employees
2009	15952	17578	90,7%	72	22,9	84,7
2010	16133	18884	85,4%	80	34,8	83,8
2011	15989	19077	83,8%	81	38,6	79,0
2012	16325	19253	84,8%	85	34,9	81,2
2013	17302	20556	84,2%	89	14,5	80,9
2014	17094	20534	83,2%	88	39,5	75,0
2015	17007	20242	84,0%	82	39,9	80,5

Source: Own elaboration with data from PIA/IBGE and Embraer Reports.

4. Government Action on the Aeronautical System of Innovation in Brazil

This section highlights the government's role in the evolution of the Aeronautical Industrial complex in Brazil. It divides its history into three periods, chronicling structural changes with a primary focus on the actions and interactions of agents. Thus, specific programs are not highlighted, although we sometimes mention some to ensure clarity and cohesion.

4.1. Period 1 – Pre-start period

The first mass-produced aircraft developed in Brazil was the Muniz M-7 made by the *Companhia Nacional de Navegação Aérea* (CNNA), in 1936. Since 1921, the owner of CNNA, Henrique Lage, tried to develop a Brazilian aircraft, but it was only possible after 1930, during Getulio Vargas's government, which established a national strategy for economic development along the lines of the structuralist theory. Getulio Vargas created the Civil Aviation Department (*Departamento de Aviação Civil* – DAC) and the

Institute for Technological Research (*Instituto de Pesquisas Tecnológicas* – IPT); these movements were crucial, establishing government demand and scientific and technological support to develop the Muniz M-7 (BERTAZZO, 2003). Moreover, the airplanes HL-1 and HL-6, also constructed by CNNA, were developed on a public procurement basis. As pointed out by Bertazzo (2003, p.10):

> *In May 1941, the newly created Ministry of Aeronautics commissioned 100 aircraft destined for Brazilian air clubs. At that time, the need for basic education aircraft was enormous, in view of the war that was developing in Europe and the prospects that Brazil could be involved in it. The company delivered all one hundred aircrafts in 1941.*

In the 1940s the *Companhia Aeronáutica Paulista* (Pignatari group) started the production of CAP-4 Paulistinha, a remodelled aircraft in whose development IPT-USP had played a major part. This aircraft enjoyed noteworthy success considering its low cost, flight quality, robustness and durability. *Companhia Aeronáutica Paulista* also developed the aircraft CAP-1 Planalto, designed also by IPT-USP.

During the same period, the government also understood that a public initiative was important to ensure the national capacity to replicate aircraft from other countries, importing technology. In 1932 a commission was created to study the implementation of a state-owned aircraft factory in Brazil (*Comissão de Estudos para Instalação de uma Fábrica de Aviões* – CEIFA), and after intense discussions toward an international partnership, an agreement was reached with a German company for the manufacture of Brazil's training aircraft (Focke-Wulf 44) and twin-engine bombardment planes (Focke-Wulf 58) in the installation called *Fábrica do Galeão*, in 1941. The efforts were halted in the early 1940s with the onset of World War II, but the Ministry of Aeronautics began negotiations with the US government shortly after to take advantage of *Fábrica do Galeão*. The aircraft selected for manufacturing was the Fairchild M-62A Cornell (220 units were produced between 1942 and 1952) (BERTAZZO, 2003). It should be noted that the incorporation of Brazilian components in the manufacturing of this aircraft increased over time, with the participation of IPT-USP in the technological maximization of both American and German aircraft.

In addition to the points already mentioned (contracts for technology transfer with foreign companies, development and maintenance of R&D centres and improvement of national productive capacity), it is important to discuss the strategy of the federal government for training Brazilian engineers abroad in the 1930s and 1940s as well as invitations for foreign professors and technicians to visit Brazil. None of these movements succeeded, however, in building up a Brazilian aeronautical industry capable of establishing national and global competitiveness. Some factors affecting this result can be highlighted.

One is that the strategies for the development of a national aviation industry followed the ideological and economic guidelines of national governments. With the change of government in 1945 and the start of term of new president General Eurico Gaspar Dutra, a more liberal orientation to economic policy was implemented, and plans for development of a national industry were relegated to the background (SARTI; FERREIRA, 2012).

The main issue that seemed to emerge for the establishment of the aeronautical industry was the lack of coordination. An innovation system able to internalize knowledge and establish an innovative national capacity with its own technology was not created. Most of the aircraft produced in Brazil originated in the licensing of projects from foreign companies or in the adaptation of imported projects. In turn, the few aircraft developed in the country were, in most cases, designed by foreign engineers. In this period, the only institution that carried out aeronautical research in the country was IPT, although it concentrated on the development of very simple experimental aircraft (SARTI; FERREIRA, 2012). As pointed out by Hausmann and Rodrik (2003, p.605), '…even when the production techniques used in the advanced countries are transparent to outsiders, their transfer to new economic and institutional environments typically requires adaptations with uncertain degrees of success'.

Still, the disconnected initiatives did not have a well-defined interaction, which pointed to the fragility of the links necessary for an innovation system able to generate satisfactory structural results. Most of the time, the companies established strategies for productive verticalization, but the aeronautical systems' complexity ensured technical and economic constraints for the continuity of their projects. That, coupled with the low demand, buried the country's possibilities.

Moreover, this lack of coordination was reflected in the companies' business strategies, with most of them operating in the same market niche or in segments whose national demand was far below the minimum technical scales required. As a result, their business strategies did not contemplate correct market niches for the evolution of the companies' competences (SILVA, 2008).

In any case, the experiences during this period provided lessons applicable to new strategies that were established from then on. Government participation in the national project needed to be better coordinated, taking into account productive, technological and commercial complementarity, the establishment of a national training strategy and the continuation of public procurement in conjunction with private demand, so as to ensure productive sustainability. Table 3 shows the actions of agents in this period, following the same pattern as presented in Table 1.

Table 3. Activities and public agents of the Brazilian aeronautical complex, Period 1

	Agents
I. Provision of knowledge inputs to the innovation process	
1. Provision of R&D results/creation of new knowledge	IPT
2. Competence building	-
II. Demand-side activities	
3. Public procurement for innovation	FAB
4. New product quality requirements	-
III. Provision of constituents	
5. Creating and changing organizations needed for new fields of innovation	-
6. Networking through market and other mechanisms, including interactive learning among different organizations involved in IS	-
7. Institutions (patent laws, tax laws, environment and safety regulations, R&D investment routines, culture norms)	-
IV. Support services for innovating firms	
8. Incubation activities	-
9. Financing of innovation, productive and commercial processes	Federal Government
10. Provision of consultancy services relevant for the innovation process (technology transfer, commercial information, legal advice)	-

Source: own elaboration.

4.2. Period 2 – The catching up period

It can be said that the understanding of the need to establish a national academic infrastructure was the basis pursued thereafter, and, six years after the birth of the Brazilian Air Force (FAB), the CTA was established. Initially made up of a training school for aeronautical engineers (ITA) and a research and development centre (IPD). As already mentioned, the inspiration came from the Massachusetts Institute of Technology (MIT), and the school quickly became a centre of excellence at the national level. Engineers trained at ITA were primarily responsible for the private companies created during the 1950s and 1960s. In addition, the Institute provided the human resources basis for the creation of the IPD within the CTA itself, in 1954, for the purpose of R&D in key areas of aeronautical application (BERNARDES, 2000).

With the flourishing of a technical-scientific base, still in the ambit of the Ministry of Aeronautics, the Institute for Industrial Development and Coordination (*Instituto de Desenvolvimento e Coordenação Industrial* – IFI) was established in 1967, as an approval and certification body, but soon it would also become an organ for the support and development of the productive base of the aeronautical industry. The demand for the institutionalization of a specific institute for these issues arose from the increase of established attributions within the IPD. In addition, the specialization of the activities created new needs, and the IPD was dismembered, giving way to the creation of the Institute of Aeronautics and Space

(*Instituto de Aeronáutica e Espaço* – IAE) in 1971 and the Institute for Advanced Studies (*Instituto de Estudos Avançados* – IEAv) in 1982.

The IPD was also the basis for the birth of the leading company, Embraer. The development of the EMB-110 Bandeirante began at the institute itself, and it was the same entity that provided the technical capacity and human resources training for the company in its productive phase, in the 1970s. The creation of Embraer as a state-owned company met the challenges and risks inherent in the production of goods of high technological complexity in an environment still embryonic and that had faced serious commercial and technological problems in the very recent past (CABRAL, 1987; FERREIRA, 2009; FRANCELINO, 2016).

It is important to note that Embraer not only was born with a well-established technical capacity, but it also conceived of a market strategy that allowed it to tap into a little-explored market, the regional one. The identification of a small aircraft market in regions with a lower economic scale guaranteed the company's ability to capture both government demand, which was vital for the first productive impulse, and the private market, considering adjustments which happened in their first orders. To this end, the government's role in establishing a law for regional aviation regulation in Brazil (SITAR in 1973) was crucial.

At that time, Embraer was already working with PPI from the Brazilian Ministry of Aeronautics for the EMB-110 Bandeirante aircraft, from the Ministry of Agriculture for the Ipanema aircraft, as well as the under licensed production of the MB-326 from the Italian company Aermacchi (known as AT-26 Xavante at FAB). It is important to emphasize the importance of establishing partnerships for military aircraft in Embraer's technological capacity. The duality in technology allowed the company to establish improvements in its commercial aviation products. The AT-26 Xavante program and later the AMX program are the main examples of the technological upgrade achieved by Embraer through military demand from the government (CABRAL, 1987; FRANCELINO, 2016).

In the specific case of the AMX program, under a specific demand of the Ministry of Aeronautics, a complementary industrialization program was created (*Programa de Industrialização Complementar* – PIC), considering the qualification of Brazilian firms for the production of certain strategic items. The qualification 'package' for national companies was composed of training activities for technical personnel, machinery acquisition, production equipment, testing equipment, laboratory supplies, special tools, technology services and technical assistance (FRANCELINO, 2016, p.156/158). In order to coordinate this program, in 1981, Brazilian Air Force constituted a commission (*Comissão Coordenadora do Programa Aeronave de Combate* – COPAC). Ferreira (2009) estimated that the FAB spent about US$ 600 million on the program, at 2009 values.

An important criticism about PIC was made by Silva (2008). The government strategy to promote the aeronautical industry was developed favouring technological transfers, implying technology import. Technological transfer, however, was not a well-regarded strategy by transnational corporations, due to the limited Brazilian market regarding size and income levels. Thus, transfers did not happen as expected. Despite this, Francelino (2016) points the improvement on IFI capabilities in coordinating projects of high technological density as a benefit.

It is important to state that Embraer's experience was different: it did not arise from adaptations of imported technologies to national conditions, eventually optimized by reverse engineering. As noted by Dagnino (1993), government investments and efforts were made to Embraer so that the latter might acquire its own productive and technological skills.

Regarding commercial issues, public-sector participation was no less important. The actions of the state-owned bank for economic development (*Banco Nacional de Desenvolvimento Econômico e Social* – BNDES) and agents supporting transverse R&D (*Financiadora de Estudos e Projetos* – FINEP as the most important) were crucial from the beginning of Embraer's operations. The FINEP financed the development of the military trainer aircraft EMB-312 Tucano and several other of Embraer's activities (FERREIRA, 2009). As pointed out by Bernardes (2000), until the 1980s the public sector was the main source of resources for R&D, accounting for about 80% of expenditures in this area.

In addition, the BNDES financed the purchase of the EMB-110 Bandeirante by civil aviation companies in Brazil after SITAR legislation (SILVA, 2008), and the bank had actively worked to assist

Embraer in export financing lines as it moved the EMB-120 Brasília forward into international markets, in the USA and Europe. Moreover, it is important to highlight the relevance that the CTA had in helping Embraer regarding international certifications so that the EMB-110 Bandeirante and the EMB-120 Brasília could operate in those markets.

To conclude the discussion on this period, it is worth to highlight the observation of Bernardes (2000):

> *The synchrony and consistency of 'mission-oriented' government policies (fiscal, tributary, industrial and technological) aimed at the sector, associated with the robust technological infrastructure created in the region of São José dos Campos, generated important learning economies and externalities, which benefited both the region and the company itself. In the 1970s and 1980s, the region of São José dos Campos, located in the State of São Paulo, underwent an era of prosperity, sustained by the development of the aerospace and war complex (BERNARDES, 2000, p. 157).*

This observation is important in two aspects: first, it shows that a mission-oriented policy had been practiced in the development of a specific industrial sector; second, that the policy had contributed to the economic development of a region.[4] In Table 4 we present the public institutions of this period, using the same pattern presented in Table 1.

Table 4. Activities and public agents of the Brazilian aeronautical complex, Period 2

	Agents
I. Provision of knowledge inputs to the innovation process	
1. Provision of R&D results/creation of new knowledge	IPD, then IAE, IEAv, INPE
2. Competence building	ITA
II. Demand-side activities	
3. Public procurement for innovation	FAB/COPAC, Min Agriculture
4. New product quality requirements	IFI
III. Provision of constituents	
5. Creating and changing organizations needed for new fields of innovation	-
6. Networking through market and other mechanisms, including interactive learning among different organizations involved in IS	COMAER, Embraer
7. Institutions (patent laws, tax laws, environment and safety regulations, R&D investment routines, culture norms)	IFI, INPI, Embraer
IV. Support services for innovating firms	
8. Incubation activities	-
9. Financing of innovation, productive and commercial processes	BNDES, FINEP
10. Provision of consultancy services relevant for the innovation process (technology transfer, commercial information, legal advice)	IFI

Source: own elaboration.

It is also congruent with observations from Pietrobelli and Rabelotti (2009) when comparing Global Value Chains and Innovation Systems:

> *Developing countries have a greater need to build the initial base of capabilities and so need to support their industry learning processes; their markets and support institutions are less*

[4] It is certain that the regional development of São José dos Campos happened by the generation of a virtuous circle. The CTA was strategic for geographic and economic reasons. The implementation of other companies during the development of the Brazilian industrial park followed the same order, mainly due to the connection between Brazil's two main cities, São Paulo and Rio de Janeiro.

> *developed, and so less responsive to enterprise needs; information networks and clusters are thinner; the macroeconomic framework for industrial and technological activity is less conducive; the entrepreneurial capacity to undertake risky technological effort may also be less developed and the financial system less geared to supporting such effort* (PIETROBELLI; RABELLOTTI, 2009, p. 217) .

4.3. Period 3 – Post-privatization period

The third phase was marked by the privatization of the largest company in the national aeronautical complex. Despite the fact that it was an important state-owned company, the bureaucratization of decision-making at government levels and the severe government budget constraints of the early 1990s, the end of the life cycle of its main products, and external factors (falling demand and increased competitiveness in regional markets) were now reducing Embraer's competitiveness.

Before its privatization, the company created incentives for the auction, and thus started a project to build a regional aircraft, the ERJ-145. Considering the fiscal crisis that it experienced, the company inaugurated a kind of relationship with supplier companies that would become standard throughout the global aviation industry, the aforementioned risk partnerships.

> *In this partnership, the risks of success (or failure) of the aircraft are shared with Embraer. Aircraft development costs are called non-recurring costs and are passed on at the price of the first aircrafts (usually 400). If the sales are smaller than expected, the partner will not recover all investment made. On the other hand, this company is practically a partner of Embraer in that specific aircraft, guaranteeing its exclusivity in the provision of such equipment/system (LIMA et al., 2005, p.45).*

At this statement, it is clear that the Aeronautical industrial complex should not be seen from a national perspective alone; it involves complex arrangements and connections regarding technological, productive and commercial strategies from a global perspective. It is frequently the national leader companies (those that integrate project designs and the assembly of the final product) that establish productive, technological and scientific hubs all over the world, exploring economies from their partner firms in a well-connected GVC (BERNARDES, 2000; STURGEON *et al.*, 2013). In this context, Embraer's main suppliers were already foreign companies, and in the establishment of risk partnerships, all those available to contract were foreign firms as well. This type of partnership was a success and continued to be used for later models of the ERJ Family.

Despite that, a huge part of the funding for the development of the ERJ-145 still comes from government budget. Of the US$ 380 million, 30% were provided by BNDES (alongside 39% from risk partners and 31% from Embraer itself). In addition, support from federal government through BNDES (specific credit lines: BNDES-Exim and PROEX-Equalization) were crucial for exports as well. The national bank created a structure to finance the export of aircraft compatible with those used by its competitors in the international market (FERREIRA, 2009).

The literature shows that the E-Jet family elevated Embraer to a prominent level of worldwide competition, and the company works with the second generation of the family today (EMB-175-E2, EMB-190-E2 and EMB-195-E2, known as E-2 family). The market entry of those aircraft promises to be quite competitive since the last one (the largest commercial airplane developed in Brazil) cost 20% less than its category, compatible with larger aircraft costs (VINHOLES, 2017).

The evolution of the company in recent years has not been mimicked in the entire industrial complex, but some initiatives point to an organised society strategy (with the inclusion of private agents and government support) to increase knowledge sectoral and technological development. The Association of National Aerospace Industries (*Associação das Indústrias Aeroespaciais do Brasil* – AIAB) was established in the 1990s, and in 2009 the Technology Park of São José dos Campos (Tech Park-SJC) was inaugurated. Its area of deployment includes national and foreign companies today, as well as new educational agents that were put into place through recent federal and state government policies, dating from the 2000s. The main universities are UNESP (State of São Paulo) and UNIFESP (federal government) but, in addition, a number of new agents have implemented courses focused on aeronautics in the region such as UNITAU, UNIVAP and ETEP, among others, since the 1990s.

The Brazilian Aerospace Cluster, executing institution of the 'Aerospace Sector Project' from the Brazilian Agency for the Promotion of Exports and Investments (*Agência Brasileira para Promoção das Exportações* – Apex) and the Brazilian Agency for Industrial Development (*Agência Brasileira de Desenvolvimento Industrial* – ABDI), was also formed in 2009, bringing together 94 companies from the aerospace and defence industrial complex (CECOMPI, 2017). In 2014, the Investment Fund for the Aerospace Sector (*Fundo de Investimento do Setor Aeroespacial* – FISA) was launched, with initial equity of R$131.3 million distributed as follows: BNDES, Embraer and Finep, each with R$40 million; Desenvolve-SP (a state development agency) with R$10 million; and R$1.3 million contributed by Portbank, the fund manager (BRASIL, 2014). In addition to increasing the number of agents operating in the Aeronautical Innovation System, these initiatives also allow for greater interaction between them, at any link in the chain.

Besides, FAB is still an important agent for PPI, especially through COPAC. In recent years, the development of the KC-390, a cargo aircraft, and the offset technology agreement for the fighter aircraft Gripen NG (F-X2 program) with the Swedish company Saab have been the main programs for AIS. The estimated budget for those programs is US$4.5 billion and US$5.4 billion, respectively (PLANEJAMENTO, 2014). In addition, since 2005, a COMAER regulation (DCA-360/1) establishes that any importation of goods or services over US$5 million must involve some compensation agreement for Brazilian companies. In this regard, the IFI has increased its capacity to control agreements that favour domestic industry.

These initiatives made it possible for the Brazilian aeronautical industry – in the figure of its leading company, Embraer – to build a high level of capacity to achieve a leading position in the international market. Table 5 below lists the real agents (public or publicly owned) in the Brazilian aeronautical complex.

Table 5. Activities and public agents of the Brazilian aeronautical complex, Period 3

	Agents
I. Provision of knowledge inputs to the innovation process	
1. Provision of R&D results/creation of new knowledge	IAE, IEAv, INPE
2. Competence building	ITA, Unifesp, Unesp, Unitau, Univap, Etep.
II. Demand-side activities	
3. Public procurement for innovation	FAB/COPAC
4. New product quality requirements	IFI
III. Provision of constituents	
5. Creating and changing organizations needed for new fields of innovation	Cecompi, Tech Park-SJC
6. Networking through market and other mechanisms, including interactive learning among different organizations involved in IS	COMAER, Embraer, Cecompi, Tech Park-SJC
7. Institutions (patent laws, tax laws, environment and safety regulations, R&D investment routines, culture norms)	IFI, INPI, Embraer
IV. Support services for innovating firms	
8. Incubation activities	Tech Park-SJC
9. Financing of innovation, productive and commercial processes	BNDES, FINEP, FISA
10. Provision of consultancy services relevant for the innovation process (technology transfer, commercial information, legal advice)	IFI, AIAB, Cecompi, Tech Park-SJC

Source: own elaboration.

Two appointments should be noted: (i) a more holistic spectrum of activities is established, (ii) now with a range of private-government interactions. Activities for provision and support not offered before now are present from those interactions, with the government's role moving from a more direct action to the support of private activity, without losing presence in important activities (regulatory, demand-side and provision of knowledge ones).

Discussions and Conclusions: from a national perspective to overall implications

The aeronautical industry tends to maintain strict links with national governments due to issues related to sovereignty and strategies to foster the industrial and technological complex (given its high technology density and many different technologies embedded in the final product) (HAYWARD, 1994). This relationship is closely related to mission-oriented policies (MAZZUCATO, 2017), since they are a crucial asset for countries. The Brazilian aeronautical industry is not different.

Our analysis stressed that public policies (industrial and innovative ones) relied upon a progressive strategy of public commitment with private agents. Changes in the form and intensity of the government's role are closely related to its sectoral evolution. In short, government participation has been progressively adapting over time.

In the Brazilian case, initially, the main aim of the government was to improve capacities (involving agents and interactions in diverse activities) to enable the emergence of this nascent industry. The initial market strategy was to act in niches, as this industry was much less competitive than the global market. Although it was fundamental to Embraer's success, this strategy was only achieved through a mission-oriented policy at training qualified human resources and carrying out significant R&D investments. In addition, we highlight the support in related activities, with emphasis on the ability to perform certifications, use public contracts (especially in the military area) for innovation and promote sales in the international market.

Over time, the strategies of the Brazilian government have been translated from a more interventionist stance to a more cooperative one. Changes in the global pattern of cooperation and competitiveness have pressed for increased profitability and innovative capacity in the Brazilian industrial sector, and Embraer's response has been through a deep and active participation into the global value chain of the aeronautical industry. This strategy of the Brazilian company has deepened the model of risk partnerships in the global aviation industry.

This is increase of international connections in the aeronautical industry centred in large assembler firms is a worldwide trend (STURGEON *et al.*, 2013). This model has led to the adoption of public policies aimed at protecting and strengthening the large national aeronautical conglomerates as a way to occupy a better position within the GVC (FERREIRA, 2009; SERFATI, 2014). However, it does not limit the role of government in promoting small and medium-sized enterprises, as is the case of the Toronto and Toulouse Aeronautical Clusters. As pointed out by Niosi and Zhegu (2005, p.22), regional clusters have become more similar to Marshallian districts, since 'large successful assemblers "attract" scores of other firms to the clusters through the creation of a large labour pool of skilled workers'.

In this context, Embraer has been one of the main successes of the industrial and innovation policy for the aeronautics industry, since it has allowed it to recover progressively over the decades. As a result, since the beginning of the 21st century, the Brazilian company has occupied a prominent position at the top of the GVC, as the third largest manufacturer of commercial aircraft in the world. Despite Embraer's successful strategy, which is closely related to GVC trends, the insertion of Brazilian companies operating at levels 2 or 3 is weak. At level 1, it is even worse, since no Brazilian company is a risk partner of Embraer or any global aeronautical automaker. This reflects the fact that the productive and innovative capacity of the Brazilian industrial complex is concentrated in its leading company.

The public policies for the aeronautical industry allowed the emergence and evolution of Embraer, which has become an increasingly active company in the GVC. However, it did not seek to establish national top-level suppliers. As a result, in the aeronautical industry, there is a group of companies that offers solutions of lower technological content for the leading company and trade insubstantially with other companies around the world. Therefore, these suppliers are quite commercially dependent on the leading company.

This strategic option allowed for a rapid evolution of the Brazilian aeronautical industry, which began to produce increasingly sophisticated aircraft, in a period in which the costs and technological complexity of this industry grew in an extraordinary way. However, this same strategic option meant that the market structure of the Brazilian aeronautical industry was concentrated in a single large company, Embraer. According to Sarti and Ferreira (2012, p.110): ‘This result should not be considered a deficiency; on the contrary, it was this concentration that allowed the technological and commercial advance of Brazil in the aeronautical industry.’

According to what is presented in item 4 of this paper, the support policy for the Brazilian aeronautical industry has been changing over time, adapting to the new needs that have arisen as a result of the advances made by this sector, concentrated in its leading company. In this context, the privatization of Embraer in the 1990s changed the company’s relations with the public sector, but it did not diminish the State’s level of involvement in the aeronautical complex. As has been seen, what happened was an increase in the active participation of public agents in interactions with the private sector. It intensified the understanding of public-private partnerships, now with more elaborate relationships supported by joint actions.

This new mode of industrial policy focused on the public-private cooperative strategy is clearer, even with national policies towards internationalisation focused on joint development of technologies. In some way, the experiences of this industry around the world follow this scheme. Regardless of the economic model, the public-private relationship is fundamental for the development of the aeronautical industry, as can be seen in examples from both the US and China.

Although the US aerospace industry has been based, from its origin, on private companies, its creation, expansion and consolidation are directly related to the public policies of support to the sector. According to Ferreira (2012, p.59): ‘The US federal government has focused its efforts on the state's purchasing power, particularly on the Department of Defense and NASA, which in the last decade has responded by more than half of this industry's sales.’ Mazzucato and Robinson (2017) highlight a shift in the US space policy, away from NASA-directed developments in low-Earth orbit (LEO) satellite towards an ecosystem with a mix of private, not-for-profit, and public actors. This is not specifically about the aeronautical market but denotes the government’s understanding about new appointments for mission-oriented policies; ‘this has fundamentally changed NASA's role from an orchestrating/directing role, to a more “facilitating” one driven by commercialization needs’ (MAZZUCATO; ROBINSON, 2017, p.1).

In China’s case, the realignment in the 1990s to a more capitalism-oriented economy was followed by a reordering of the state in the sector, but still with public firms (particularly the Commercial Aircraft Corporation of China – COMAC – and its parent company, the Aviation Industry Corporation of China – AVIC) and heavy investments in both defence sector and civil aviation. Still, in 2007 the Chinese government promoted a shift in strategy for the large civil aircraft industry, from ‘market in exchange for technology’ to ‘independent innovation’ (CHANGXI, 2016; GORDON, 2008; HAYWARD, 2013). In this new context, projects like the C919, which intend to compete with the world leaders – Boeing and Airbus – to break the existing duopoly, stand out (MINTER, 2017). This change represents an increase in creating internal capabilities by which the government tends to have greater decision-making power.

Even with distinct levels of intervention, the cases of US and China mentioned above point out that the form of government intervention is realigned over time according to firms’ competitive improvement. These remarks do not represent any general formula of public policies for the aircraft industry. However, it is clear from these examples that public policy shifts as new results are achieved and new goals are being set, in line with a well-established mission-oriented innovation policy. Hence, the need for evaluation and adjustment can be seen as a more general lesson from this paper, and the role of government intervention emerges as a particular strategy for each nation-state. But it is certain that, from a more centralized state action – as in the Chinese case – to a more balanced and complementary action to private strategies – as in the case of US and Brazil – a government's understanding about the relevance of its action and the need of not exempting itself from engaging in policies that foster its national industry is crucial.

The main challenge for the Brazilian aeronautical complex is to guarantee and strengthen Embraer so that it will continue to have an active participation in the GVC. In this sense, if Boeing's current proposal to acquire Embraer's commercial aviation business is implemented, it will certainly lead to the dismantling of the leading company of the Brazilian aeronautical industry, with negative results for the industry as a whole (EXAME, 2018). Public policy must also promote the growth of national companies, making them capable of operating in global value chains. In this sense, contributions such as the Embraer partnership with public agents, IFI's ability to deal with technology compensation projects, the technology park and the aerospace cluster are examples that have beneficial effects throughout the production chain. Finally, the resources necessary to maintain the KC-390 and F-X2 programs must be maintained, as they are strategic, not only for the military area, but for the Brazilian aeronautics industry as a whole (DEFESANET, 2017).

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