

How public policies have shaped the technological progress in the Brazilian aeronautics industry: Embraer case

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Abstract

Despite the growing interest in Embraer, the Brazilian world leading aircraft manufacturers, little empirical research exists on the role of Public Procurement for Innovation (PPI), in Brazil, on the shaping of technological capabilities of the aeronautics industry. To capture those impacts, developing a methodological approach is necessary. Thus, the objective of this article is to evaluate the impacts of PPI on Embraer over the last forty years, developing a model for categorizing and analyzing the general technological aspects of those impacts, implemented through Brazilian Defense Acquisition Programs. The results suggest that the Brazilian Aeronautical Policy led to the development of very specific technical capabilities in Embraer, which allowed its evolution in civil aviation.

Key words: Brazilian Defense Programs; Public Procurement for Innovation; technological capabilities; aeronautics industry; Embraer; technological impacts.

1. Introduction

The positioning of Embraer—a firm from a late-industrializing country—in achieving a recognized leading role at the world aeronautical industry can be credited to the combination of two main factors. First, over the years, the firm reached a high level of technological capabilities in system architecture development, engineering, and integration, with great understanding of the aeronautical market for the development of the requirements of its customers and outstanding focus on key technologies of proprietary domain (Chagas Jr et al. 2017). Second, Embraer's technological capability for cutting-edge technological knowledge has emerged, in several cases, as a response to public procurement policies, particularly from the Brazilian Aeronautics Command (Comando da Aeronáutica [COMAER]). The public sector orders give a favorable environment for the development of innovative technological capabilities (Cassiolato et al. 2002).

Traditionally, studies on innovation policy initiatives have come mainly from the supply side; however, in recent years studies on the demand-side approaches of innovation policy are arousing more interest (Edquist et al. 2015). Public Procurement for Innovation

(PPI), a demand-side innovation policy instrument, is represented largely by orders requested by public organizations for a new product or the improvement of specific needs (Aschhoff and Sofka 2008; Edler and Georghiou 2007; Edquist et al. 2000). It could be understood as the procurement decisions of public organizations leading to any kind of innovation and a suitable policy to contribute to achievement of grand challenges (Chicot 2017). In addition, public organizations can act as lead users, they are willing to pay a premium for innovative products and services and contribute to make environments more favorable to innovation (Chicot 2017).

Consequently, PPI can have positive effect on innovation by stimulating the creation of markets (Box 2009; Edler and Georghiou 2007; Edler and Uyerra 2013; Rothwell 1984). In the Brazilian case, the government support through PPI has been vital to turn Embraer, the main firm of the Brazilian aeronautics industry, into one of the world leading aircraft manufacturers. The development of strategic technologies through the purchase power of the State is something usual with other firms around the world. In the current context, in which Boeing (America's biggest manufacturing exporter) is offering to acquire Embraer or part of it,¹ it is worth noting the importance

of PPI for Embraer's technological development over the years. How have public policies shaped the process of technological progress in the Brazilian aeronautics industry? The review of the academic literature shows that the impacts of public programs on technological capabilities at a micro-level approach have not been focused in academic research, which opens opportunities for new evaluation formulations.

Given this context, this article reviews the scientific literature and does not find any appropriate methodological approach to perform an analysis of the impacts of PPI in Embraer. Analytical frameworks to explore the impacts of Defense Programs on the aeronautics industry are scarce, especially those on the accumulation of technological capabilities. Thus, considering the literature about technological capabilities that provides models for visualizing the technological capabilities at firm level and their evolution over time, we propose a new research stream derived from merging the Theory of Technological Capabilities Accumulation (Bell and Pavitt 1992, 1993, 1995; Figueiredo 2002; Lall 1992) and the Theory of Evaluation Public Innovation Programs inspired in the Bureau d'Economie et Théorique Appliquée (BETA) Methodology (Bach 2012; Bach et al. 1992). Based on a new use of technological matrices, it is possible to evaluate the impacts of public procurement programs, through the identification of gains on firms' technological capabilities at the micro-level.

The main objective of this article is to present an evaluation of the technological capabilities created by Defense Programs in Embraer. We analyze all the Military Aircraft Programs since the 1980s until nowadays, such as the Programs AM-X, AL-X (Super Tucano), F5-BR, and KC-390. The Defense Programs are mentioned here as a synonym of Military Aircraft Acquisition Programs of Brazilian Aeronautics Command, and as a gauge of explicit aeronautics policy in Brazil on the demand side. In this sense, the COMAER has been managing several programs for the last forty years, including the development of complex systems that have induced technological leaps in Embraer. Embraer was the prime contractor of all these programs for the development and production of military aircrafts in Brazil. Throughout these years, a strong partnership was established between the COMAER and Embraer.

The AM-X Program (1982–94) was an important acquisition program developed with the specific goal of improving the development of the Brazilian aeronautics industry. This program was performed in partnership with the Italian Ministry of Aeronautics and its aviation industry (Aeritalia and Aeromacchi). This process gave Embraer a unique opportunity to absorb technological knowledge and to improve its workforce qualification in cutting-edge knowledge. During the 1990s, Embraer developed the Super Tucano (AL-X) following COMAER's requirements, and it remains an amazing case of sales success all over the world until nowadays. The Super Tucano is a turboprop light attack aircraft for advanced training, which incorporates the latest advances in avionics and weapon. This aircraft was designed to meet the operational requirements of the Brazilian Air Force for a tactical attack, capable of operating in the Brazilian Amazon rainforest as well as being suitable for the training of beginner fighter pilots.

Embraer was also contracted for the F5 Aircraft Modernization Program. The first fleet from the 1970s and the second fleet from the 1980s were both purchased from USA, and the third fleet was acquired in the 2000s from Jordan. The modernization of these aircrafts required the incorporation of current technology for avionics, armament, and sensors. This program generated the Offset Plan for the purchase of Aeroelectronica, a Brazilian avionics firm, by the

Israeli company Elbit. Currently, the most important Defense Program is the KC-390 Program, entirely designed by Embraer (US \$2 billion of agreement, signed in 2009). The KC-390 will replace the Hercules C-130 aircraft, which is broadly used in the Brazilian Air Force. The aircraft is designed for several kinds of missions, such as search and rescue, transportation, refueling, launching cargo and paratroopers, medical evacuation, fighting forest fire, among others. The KC-390 is a large size high-wing aircraft, with jet engines, capable of landing on unpaved and unprepared runways, conceived with cutting-edge technological knowledge from many areas. Among the innovations, the tank jet can be refueled and refuel in flight, including helicopters and land in Antarctica. The KC-390 is the only aircraft in its category that has electronic Fly-by-Wire system, which provides greater efficiency for pilotage and integration with other missions.

This sequence of Brazilian Defense Programs leads us to believe that the support from the Brazilian government was relevant for Embraer's technological development and also for their suppliers in Brazil. They promoted the accumulation of technological capabilities that allowed Embraer to master the dominant technologies at each moment of its trajectory. The Evaluation Matrix of the Impacts on Technological Capabilities (EMITeC), proposed here, is a methodological framework designed to evaluate the impacts of Brazilian Defense Programs on the technological path of firms that participated in a series of public programs. EMITeC allows the visualization of technological capabilities that were actually created or enhanced by the programs in the contracted and subcontracted firms. This evaluation approach configures a novelty for the main-stream evaluation, since the Model analyzes impacts at the level of the firm's main technological capabilities. The constituent elements of EMITeC are the technological functions considered vital to the elevation of the technological complexity of aeronautics firms from late-industrializing countries. The development of the Model is based on multiple methodological procedures, such as in-depth fieldwork and documentary and bibliographical research. Then, the model is applied to Embraer for each technological function. We investigated if the participation of Embraer in Defense Programs led to the development of its technical, sustaining, and organizational technological capabilities, according to the EMITeC categories.

Section 2 will briefly discuss the gap in the evaluation literature and the opportunities opened by the Theory of Technological Capabilities. Section 3 shows the research design and method, explaining in detail what kind of research instruments and sources were used. Section 4 will present the results, the proposed Model for evaluating Defense Program's impacts—EMITeC—and the evaluation of impacts of Defense Programs on Embraer's technological path. Section 5 will present the discussion of what kind of insights this evaluation provides. Finally, the article presents research conclusions of the relevance of Defense Programs on Embraer's trajectory.

2. Background and literature review

The evaluation of impacts provided by Public Programs is a demand from the society, government, and funding agencies, to evaluate the use of public funds and the design of strategic policies (Montoro et al. 2009; Rauen 2017). Preferably, such evaluation should consider the impacts at a micro-level approach, that is, the unit of analysis is the firm. Most evaluation approaches focus on the discrete products of the program; they rarely consider the changes in people,

institutions, and the process of building innovative technological capabilities at firm level. According to [Bozeman and Kingsley \(2013\)](#), regarding economics analysis, if someone is interested in the capability created by a Research and Development Program or in its transformational impacts, then cost-benefit or rate of return approaches provide only limited insights. Product-oriented and output-focused evaluations tend to give a short shrift to the generation of capability in science and technology, and to the ability to produce sustained knowledge and innovations ([Bozeman and Kingsley 2013](#)).

The academic literature of program evaluation presents a wide range of methods and methodologies. According to [Link and Vonortas \(2013\)](#), the mainstream evaluation techniques include surveys, statistical and econometric estimation, patent analysis, bibliometrics, scientometrics, network analysis, cases studies, historical tracing, and expert judgment. The evaluation methods of programs and policies can be categorized as Economic—economic analysis of the impact ([Link and Scott 2013](#)), econometric methods ([Arvanitis 2013](#)), selection of the portfolio of R&D projects ([Casault et al. 2013](#)); Non-Economic—peer review and expert panels ([Feller 2013](#)), logic modeling ([Jordan 2013](#)), research value mapping ([Bozeman and Kingsley 2013](#)); Hybrid—social network methodology ([Vonortas 2013](#)), estimating emissions avoided environmental health benefits ([O'Connor et al. 2013](#)), evaluating cooperative research centers ([Rivers and Gray 2013](#)); Data-Driven—bibliometrics ([Hicks and Melkers 2013](#)), patents analysis ([Ruegg and Thomas 2013](#)), and innovation surveys ([Jankowski 2013](#)). The diversity of approaches relies largely on the objectives of the public program and on the availability of information and its level of aggregation. The mainstream methods do not allow the evaluation of impacts on the development of technological capabilities at firm level. In addition, aggregated and non-aggregated public data about public intervention are very scarce.

Another approach that stands out in academic literature on program evaluation is the BETA Methodology ([Bach et al. 1992](#)), with interesting applications in Brazilian cases ([Furtado and Costa Filho 2009](#); [Furtado et al. 1999, 2008](#); [Hasegawa 2005](#); [Miranda 2008](#); [Rocha 2014](#)). BETA was initially developed to capture indirect social and economic effects resulting from large investments in the European aerospace industry. This method allows the identification of the indirect effects of programs, considering technological, commercial, competitive, and organizational effects, as well as effects on human resources. The indirect effects are the result of a learning process derived from the sedimentation of the organizations' technological capabilities ([Furtado et al. 2008](#)). Although BETA considers the development of technological capabilities to be relevant for the evolution of the maturity of organizations, the evaluation of these capabilities is not performed by BETA because these capabilities remain subjacent to the evaluation approach.

For highly complex programs, the technological capabilities developed by the program are key aspects to evaluate the public investments. Thus, it seems appropriate to use an alternative Construct that could capture the impacts in terms of the development of technological capabilities.

2.1 The Theory of Technological Capabilities Accumulation: new opportunities of applications

The Theory of Technological Capabilities Accumulation allows the user to perceive what happens at firm's level, in terms of innovation activities, and how the evolution of technological maturity occurs in

firms from late and newly-industrializing countries that are looking forward to overcome technological underdevelopment (catching up). The first studies of the Theory of Technological Capabilities Accumulation started in Latin America and later in Asia during the 1980s ([Bell 1984](#); [Dahlman 1984](#); [Fransman and King 1984](#); [Katz 1984](#); [Lall 1984](#)). The concept of technological capabilities is fundamental for this approach, it is defined as a firm's organizational resources to create, adapt, manage, and generate technical change ([Bell and Pavitt 1993](#)). According to [Figueiredo \(2004\)](#), technological capabilities are accumulated in four basic building blocks of capabilities: (1) physical technical systems; (2) knowledge and qualification of people; (3) organizational system; (4) products and services. This concept is a practical way of dealing with [Penrose's \(1959\)](#) firm's resources.

The Theory of Technological Capabilities uses Technological Capabilities Matrices to allow the investigation of such capabilities in the fieldwork. Lall's Technological Capability Matrix (1992) is the most widespread model utilized in empirical studies. The Matrix is a way of categorizing and evaluating a firm's technological capabilities according to specific functions and degrees of indicative complexity. The main functions that must be internalized by firms to obtain commercial success in a given operation are located in the columns of the Matrix. The degrees of complexity (basic, intermediate, and advanced) are arranged in the lines. These degrees are only indicative; therefore, it is difficult to judge a priori if the functions are simple or complex. Lall's Matrix does not present an exact sequence of technological learning, and the functions proposed by him do not exhaust all the possibilities of functions ([Lall 1992](#)). Lall's Matrix was constructed under three broad categories of capabilities: Investment, Production, and Linkages with the Economy. The functions explain what the firm really needs to master to achieve a certain technological level. The Matrix allows the technological capability to be identified and categorized from the activities performed by the firm throughout its existence.

During the 1990s and 2000s, a new generation of researchers, such as [Dutrénit \(2000\)](#), [Figueiredo \(2001\)](#), [Hobday \(1995\)](#), and [Kim and Nelson \(2000\)](#), refined and expanded the analytical models of technological capabilities accumulation and applied them to several industries. [Figueiredo \(2002\)](#) was responsible for the empirical operationalization of the Matrix of Technological Capabilities Accumulation. The functions of his main Matrix are (1) Investments, (2) Processes and Production Organization, (3) Products, and (4) Equipment. Each function was unfolded according to the following levels of technological complexity: (1) Basic, (2) Renewed, (3) Extrabasic, (4) Pre-intermediate, (5) Intermediate, (6) Upper Intermediate, and (7) Advanced. The model differentiates routine capabilities and innovation technological capabilities, according to [Bell and Pavitt \(1995\)](#) requirements, which is critical for the fieldwork in empirical studies.

According to [Bell and Pavitt \(1995\)](#), innovation capabilities mobilize firm's resources for innovation activities, turn ambitious changes possible. Production capabilities mobilize firm's resources to produce industrial goods, at a determined level of efficiency and inputs (equipment, skills, specifications, methods, and organizational systems). This differentiation provides relevant insights to the development and deepening of technological capabilities that enable technological change, and it can be very useful for designing sectorial policies to encourage innovation.

According to [Bell and Figueiredo \(2012\)](#), the technological capabilities accumulation is the most critical activity for late-industrializing countries, especially because they start their activities from

imported technology. Thus, in the early stages, when firms or countries often lack the basic production technological capabilities, the issues of technological learning must be reinforced. This is an evolutionary and cumulative process with deliberate learning efforts. The process tends to be cumulative throughout a long-term trajectory, in which the past learning reinforces the stock of existing knowledge and expertise, contributing to the direction of technological change.

Figueiredo has proposed an interesting set of descriptive models, which include important production and innovation functions to analyze the evolution of technological capabilities of different industries, such as steel, capital goods, technology information, pulp and paper, sugarcane, mining, among others (Castro and Figueiredo 2005; Figueiredo 2001, 2002, 2004, 2005, 2006, 2008, 2009, 2010, 2014; Figueiredo and Piana 2016; Tacla and Figueiredo 2003). Marques (2011), Marques and Oliveira (2009), and Oliveira (2005) applied Matrices of Technological Capabilities to aeronautics industry. However, the matrices proposed by these authors did not consider some functions that are essential for the aeronautics industry. These studies focused on analyzing the situation of the firms considering their levels of technological capability. They also have the potential to be used as an instrument to evaluate public programs, with the need to adapt and incorporate the functions that are relevant to the aeronautical sector and with the appropriate methodological adaptations to capture the impacts of public programs in the evolution of the functions.

3. Research design and method

The objective of this article is to evaluate the impacts of Brazilian Defense Acquisition Programs on the evolution of Embraer's technological capabilities over the last forty years. The evaluation was done through the Model designed for capturing the impacts of public programs at firm level, the EMITeC. The Matrix united two avenues of research, the Theory of Technological Capabilities Accumulation and the Theory of Evaluation Public Innovation Programs inspired in the BETA Approach. Consequently, it is possible to perform the evaluation of the impacts on technological programs through the identification of gains on technological capabilities. The constituent elements of the Model are the technological functions considered vital to the elevation of the technological complexity of aeronautics firms of late-industrializing countries and could be impacted by the purchase policy of the Brazilian Aeronautics Command as a PPI.

The development of the Model is based on multiple methodological procedures, of interactive and iterative nature, such as revision of the academic literature, meetings with specialists of the aeronautics sector and Embraer, fieldwork in military organizations, such as the Coordinating Commission of the Combat Aircraft Program (Comissão Coordenadora do Programa Aeronave de Combate [COPAC]), the Institute for Industrial Development and Coordination (Instituto de Fomento e Coordenação Industrial [IFI]), and aeronautics firms (Table 1). During this phase, the most appropriate procedures to collect the data and information that can perform the evaluation were identified.

All the military aircraft programs since the 1980s until nowadays were analyzed, such as the Programs AM-X, AL-X (Super Tucano), F5-BR, and KC-390. The Tucano Program is out of scope because the contracts were not in the COPAC archives, in Brasília. Embraer was a prime contractor of all these programs for the development and production in Brazil. Almost 340 h of interviews were

conducted, including a research internship at the COPAC and IFI to collect data on the programs and firms contracted and subcontracted by Embraer. At the COPAC, the Memorandums of Understanding between Brazil and Italy for the AM-X Program were analyzed, as well as the main contracts for the AM-X, AL-X, and F5-BR Programs and the AM-X Program of Complementary Industrialization, a training program of the COMAER. At the IFI, the Business Analysis Questionnaire (Questionário de Análise Empresarial; QAE) was analyzed, which contains detailed information on the aeronautics suppliers.

The interviews were conducted with presidents, directors, managers, engineers, specialists from 2011 to 2017:

- Vice Presidency of the KC-390 Program of Embraer (2016).
- Subcontracting Department of Embraer, which deals with Brazilian suppliers (2016).
- Strategic Industrial Manager of Embraer (2016).
- Eleb (director and engineering team), the manufacturer of landing gear in Embraer (2015).
- AEL Systems (director of technology), firm specialized in avionics (2015).
- The founder of Embraer, Ozires Silva (2014).
- The civilian and military employees of COPAC—program managers and team (2011 and 2012).
- The civilian and military employees of IFI—Departments of Business Analysis and Offset Agreements (2013, 2014, 2015, and 2016).
- Small- and medium-sized machining firms subcontracted by Embraer (2014, 2015, and 2016).
- Specialists from the National Institute for Space Research—Instituto Nacional de Pesquisas Espaciais (INPE) (2017).

The main impacts of the Defense Programs on Embraer's technological path were investigated, as well as the difficulties, frailties, and challenges for the supply chain, located in Brazil. As shown in Table 1, semistructured interviews with Groups 1, 2, and 3 were conducted. The instruments of this research are also based on participations in lectures, seminars at Embraer (PDCA: Program for the Development of the Aeronautics Supply Chain), Centro para a Competitividade e Inovação (CECOMPI), Technological Park of São José dos Campos, IFI, INPE, and visits to the firm's productive area. The following research questions directed the research.

Research questions:

- How Defense Programs impacts can be evaluated considering the technological capabilities generated at firm level?
- What are the appropriate methods to evaluate the impact at micro-level approach?
- What data should be collected to evaluate technological capabilities impacts?

4. Results

This section presents the Model EMITeC for evaluating the impact of Defense Acquisition Programs on the accumulation of technological capabilities at firm level. Then, the evaluation instrument is adapted and applied to the Embraer case.

4.1 The EMITeC

The literature review inspired the adaptation of the Matrix of Technological Capabilities for the new purpose of evaluating the impacts of Defense Acquisition Programs at micro-level approach

Table 1. Research instruments, sources of data, and interviews of fieldwork.

General panel of sources		
	Sources	Description
Bibliographic research	1. Available literature	PhD theses, master’s dissertations, monographs, journal articles, books, book chapters, sector studies on technology program evaluation, Theory of Accumulation Technological Capabilities, Matrices of Accumulation of Technological Capabilities of various industries, PPI, Defense Acquisition System, defense programs, project management, maturity models (CMMI), Brazilian aeronautical industry, Embraer, machining, manufacturing, special processes, aircraft parts, certification
Documentary research	2. Official documents	Brazilian Aeronautics Command Guidelines, Instructions, Regulations, Contracts, Embraer’s list of suppliers (COPAC, IFI, CECOMPI, Agência Nacional de Aviação Civil (ANAC)), Ministry of Defense guidelines, laws, studies, Business Analysis Questionnaire (QAE) of IFI
	3. News and media	Internet portals specialized in Defense and aeronautical industry, websites of the firms, Brazilian Aeronautical Command, IFI, Agência Brasileira de Desenvolvimento Industrial (ABDI), Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTI), CECOMPI, ISO Certification, NADCAP Certification
Fieldwork	4. Semistructured interviews with Groups 1, 2, 3	Group 1. Military organizations: COPAC, IFI Group 2. Academic Specialists: Aeronautics Institute of Technology, Polytechnic of University of São Paulo, University of Strasbourg, University of Brasília, National Institute for Space Research Group 3. Executive Specialists: Ozires Silva, Embraer, Eleb
	5. Direct observation in productive area	Embraer, Eleb
	6. Participation in lectures and seminars	Embraer, CECOMPI, Technological Park of São José dos Campos, IFI

(Francelino 2016). This is possible because it can be assumed that the evolution of the technological capabilities of the firm over time, described by the Matrix, can be attributed to the influence of various Defense Acquisition Programs. However, since the Matrix is a representation of the technological path followed by the firm, to use it as an evaluation tool it is necessary to complement it with investigative procedures, allowing the identification of whether the source of a given upgrade on a technological function can be attributed to the implementation of a specific Defense Program. Thus, the research design used in this article, which combines the construction of a Matrix (EMITeC) with in-depth fieldwork, as well as documentary and bibliographical research, allowed the use of the Matrix of Technological Capabilities as a new instrument to evaluate the impacts of Public Programs on the technological path of firms.

EMITeC is based, essentially, on evolutionary literature, on the Matrices of Technological Accumulation and concepts developed by Bach et al. (1992), Bell and Pavitt (1992, 1993, 1995), Börjesson et al. (2014), Figueiredo (2014, 2001, 2002, 2004, 2008, 2009), Fleury and Fleury (2003), Hasegawa (2005), Lall (1992), Marques (2011), Oliveira (2005), Penrose (1959), and Yoruk and Yoruk (2012). The main functions are located in the columns of EMITeC, which translate the firms’ resources regarding activities, defined processes, allocated human resources, and equipment. This is a concrete form of seeing the firms’ resources, as defined by Penrose (1959). The identification of the functions and activities of the EMITeC developed for Embraer was obtained through intense dialog with knowledgeable specialists. The nine main functions proposed are:

- Product Development: subdivided into system architecture development, avionics, flight controls, flight test, and integration.
- Manufacturing Engineering (Processes and Equipment).

- Management Technological Capabilities Accumulation.
- Diversification—Capabilities for Global Operation and in Other Markets.
- Formal Networks of Development.
- Production Management.
- Project Management.
- Innovation Management.
- Supply Chain Management.

We must highlight that these functions are grouped according to their intrinsic nature—technical, organizational, and sustaining (Table 2). The Technical Functions are unfolded into Product Development (system architecture development, avionics, flight controls, flight test, and integration) and Manufacturing Engineering (Processes and Equipment). The Organizational Functions are unfolded into Production Management, Project Management, Innovation Management, and Supply Chain Management. The Sustaining Functions are unfolded into Management Technological Capabilities Accumulation, Diversification—Capabilities for Global Operation and in Other Markets, and Formal Networks of Development. The novelty, in contrast to other models existing in the Theory of Technological Capabilities Accumulation, is the explicit inclusion of the managerial dimension of the technological capabilities accumulation process. This complementation is a step forward on what Figueiredo (2001, 2002) did. It is an attempt to capture clearly the management ability to plan and to coordinate the path evolution of the firm’s technological capabilities accumulation. Thus, this function can be seen as a dynamic capability (Teece et al. 1997), because it is expected that it combines, constructs and reconfigures, harmonizedly, firm’s resources, allied with external resources, into innovative capabilities, throughout the firm’s process of capability building. Thus, it expressly manages the firm’s internal and external resources,

Table 2. The proposed technological functions of EMITeC for Embraer.

EMITeC: Firm-level evaluation tool		Sustaining functions					Organizational functions			
Types of technological capabilities complexity	Levels of technological complexity	Technical functions		Sustaining functions			Organizational functions			
		Product Development	Manufacturing Engineering (Processes and Equipment)	Management Technological Capabilities Accumulation	Diversification— Capabilities for Global Operation and in Other Markets	Formal Networks of Development	Production Management	Project Management	Innovation Management	Supply Chain Management
Innovative Technological Capabilities Routine	Advanced Intermediate	Activities, defined processes, allocated human resources, and equipment. Expresses the structure of engineering for product development.	Activities, defined processes, allocated human resources, and equipment. Expresses the complexity of the parts produced. The potential of machinery. Ability to develop new processes	Activities, defined processes, and allocated human resources. Expresses the continuous planning and coordinating of the resource's base evolution, through integration, building, and reconfiguring of internal and external resources to achieve innovative capabilities.	Activities, defined processes, and allocated human resources. Express the structure for a systematic search for new markets and new opportunities inside and outside Brazil, in the aeronautics industry or in other industries	Number of contracts, technological content. Express the formal agreements with external organizations, such as other firms, research institutions, and the government. Formal contracts for development activities with high-level organizations	Activities, defined processes, allocated human resources, and equipment. Project management processes. ERP (Enterprise Resource Planning) with a good execution status. Lean tools. Advanced quality tools. Continuous use of Mapping Stream Value	Activities, defined processes, and allocated human resources. Project management processes. Formal qualification level. Stages of Kerzner (2005) Model	Activities, defined processes, and allocated human resources. Structure of R&D. Presence of manager of innovation, teams of innovation, involvement of the whole organization. R&D and innovation projects. Innovation tools: discussions, forums, seminars, innovation rooms, Good Ideas Program, Innovation Committee, regular meetings of the board and leaders, project office	Activities, defined processes, and allocated human resources. Supply chain management process. Mastering the operations related to the special processes (NADCAP certification). Verticalization trend for special process

Sources: Adapted from Lall (1992), Bell and Pavitt (1995), and Figueiredo (2002). Own elaboration based on research (Francelino 2016).

supporting the continuous generation of innovations. Therefore, the inclusion of Organizational and Sustaining Functions relevant to the aeronautics sector is an advance in the direction to endogenize functions that organize and manage the development of innovations and the technological capabilities as a whole.

The Technical Functions cover technical activities related to the firm's main activity. The Product Development Function includes activities to develop new products or services, this area is responsible for generating capabilities in the internal environment of the firm, which allows the incremental or radical innovation in the medium or long term. The main areas of Embraer's efforts are encompassed in this function, such as system architecture development, avionics, flight controls, flight test, and integration. The Manufacturing Engineering Function relates to the activities of process engineering of a machining firm (cutting, milling, turning, mechanical assembly, grinding, mechanical adjustment, etc.) and the particularities of the equipment used (lathes, milling machines 2, 3 4, 5 axes, multitasking).

The Organizational Functions encompass activities that allow the efficient use of resources, the promotion of innovation, and supply chain management. The Production Management Function refers to the activities of coordination and production management, quality control, continuous processes of improvement (Lean), efficient production management, through the rationalization and optimization of production processes. The Project Management Function deals with project routines to meet deadlines, customer requests, procedures, seeking the improvement of the coordination of projects inside the organization, this function used the levels defined by [Kerzner \(2005\)](#). The Innovation Management Function is critically relevant to allow the firm being innovative and sustainable in the long term. The Supply Chain Management Function focuses on the special processes that require specific certifications.

The Sustaining Functions include activities considered vital to the technological development of firms, in terms of innovative technological capabilities. The Management Technological Capabilities Accumulation Function allows the firm to create mechanisms for the acquisition of internal and external knowledge, as well as its socialization and codification. This function summarizes the main channels of technology acquisition for firms of late-industrializing countries: Arms' Length Relations (as a way of accessing the supplier's encoded external knowledge); collaboration agreements (as a way of accessing tacit external knowledge of specific agents); endogenous activities, that is, the effort to develop the firm's own capability for technological evolution (activities for problem solving, research, and development); and, the level of qualification and experience of the firm's employees. The Formal Networks of Development Function focus on the formal instruments, which allows the firms' relationship with external high-level organizations, that is, other firms, research institutes, laboratories, universities, etc. The Diversification Function—Capabilities for Global Operation and in Other Markets emphasizes the firm's ability to diversify in other markets, especially in global operations, and in other related industries in the same country that use the same resource base.

The underlying hypotheses of the developed Model are that the strategic and systematic management of Sustaining Functions supports the process of technological capabilities accumulation, and that process could be reinforced by the participation in Defense Programs. Consequently, the impacts of Defense Programs can be associated to the evolution of the technological maturity of Brazilian aeronautics firms.

The levels of complexity are located in the lines of EMITeC Model. For the case of Embraer, even though the links between the

functions and the levels of complexity are difficult to unveil through the interviews, there were defined six levels (three Basic Levels, Pre-intermediate, Intermediate, and Advanced), based on findings supporting such unfolding of complexity levels, for the Brazilian aeronautics supply chain ([Francelino, 2016](#)).

The information collected to construct the matrix ([Table 1](#)) included bibliographic and documentary research, emphasizing several reports about the Defense Programs and its expectations about technological development, as well as about the impacts they have promoted in Embraer's trajectory. In addition, information was collected through fieldwork at different times, performing interviews with specialists and managers of Embraer, Military Organizations, and academic researchers. Thus, it was possible to reach an adequate understanding for the proposed functions, in terms of their objectives and main capabilities, taking into account the evolving complexity of these functions. All those functions could be seen as intertwined capabilities, working together to integrate Complex Product Systems ([Chagas Jr et al. 2011](#); [Hobday 1995](#); [Hobday et al. 2005](#)). However, it was not possible to measure the complexity level of each observed Defense Program's impact in Embraer case. Even so, it can be pointed out that the systematization of Technological Functions for Embraer, as proposed in the EMITeC Model, constitutes a very valuable material and an advance in the literature. It can be expected that the evolution of those technological capabilities for Embraer should be orchestrated to evolve in concert to the innovation challenges of the firm.

In the conceptual foundations of EMITeC Model it is important to emphasize that the Technological Functions are interwoven, which turns their progression on the maturity scale interdependent. However, since it is difficult to observe empirically the relationships among the different functions, it can be assumed that at Embraer there is an orchestration of the functions' evolution. In fact, when the firm strives to develop an engineering department, focused on the development of radical innovations in its product network, it has to use an already systematized and organized structure of functions with levels of maturity compatible among them. In this sense, the resources and activities involved in the Management of Technological Capabilities Accumulation are crucial, as well the structure and the numerous tools for innovation management.

In the specific case of the Innovation Management Function, the Model was designed to identify the level of integration of innovation tools and systematized activities that the firm performs. Embraer has a wide range of activities that take place in parallel with the main activity of the firm, which essentially seeks to stimulate the creation of new ideas and applications. These activities need to be internalized in the routine of the firm, within the Innovation Management Function, in order to achieve more effective results in terms of innovative performance. In other applications of the Model ([Francelino 2016](#)), it found that the lack of integration and connection of these activities throughout the firm environment does not generate innovations, culminating in a lower level of maturity, which ultimately demonstrates the lack of defined and systematized processes to the pursuit of innovation. Thus, in EMITeC perspective, an activity of the Innovation Management Function can become routine, however, what makes difference in the development of innovations for the firm is the level of integration and complexity of this activity with other activities of the firm, as well as the fact that firm's innovation development is heavily dependent on the level of integration and complexity of all technological functions.

In [Table 2](#), we present the proposed Technological Functions of EMITeC for Embraer.

4.2 Brazilian Aeronautics Command's structure to manage the Defense Programs and relations with Embraer

This subsection aims to provide some precisions in order to get a deeper understanding of the way the PPI tool has been implemented, and how it has specifically influenced the evolution of Embraer.

The Directive of Aeronautics Command—Diretriz do Comando da Aeronáutica (DCA) 400-6 (Brazil 1992) is the main document that regulates the acquisition of a weapon system or strategic defense equipment in the Brazilian Aeronautics Command. The first version of the DCA dated of 1992 and the last updated version was in 2007. DCA 400-6 orders the planning, execution phases and key events in the life cycle of a system or an aeronautical material and regulates the technical performance, integration, and accountability of units of COMAER that intervenes in the acquisition process. According to DCA 400-6, the life cycle of aeronautics systems and materials consists on the phases of design, feasibility, definition, development or acquisition, production, deployment, use, revitalization, modernization or improvement and deactivation (Francelino et al. 2015).

It is the guideline of life cycle of aeronautics systems and materials that stipulates the tasks and organizes the activities by defining who and what to do. The Subdepartment of Development Program was responsible to introduce how to do. DCA 400-6 is the main document that contains the phases inherent to the process of acquisition defense systems, with its principal documents, activities, and responsible agents. This guideline is based on the best practices that have been already established, especially in the USA (Francelino et al. 2015).

The decision to acquire a weapon system for the Brazilian Air Force² is the Commander of the Aeronautics Command (COMTAER) advised by the Staff of the Air Force (EMAER). The overall coordination of system acquisition programs or materials is the EMAER. The direction of the program is designated by EMAER. The execution is the responsibility of the subordinate bodies and Sector Director Direct and Immediate Assistance of the Aeronautics Commander (Órgão de Direção Setorial e de Assistência Direta e Imediata ao Comandante da Aeronáutica; ODSA) or hired firms or linked organizations. The management of the programs is determined by COMTAER, the program manager, aided by a team of experts, is responsible for driving the unit and integrates program design. The manager is also responsible for establishing the functions of supervision and control until the delivery of material or system. After the deployment phase, the responsibility of management the program is transferred to the ODSA (Francelino et al. 2015).

The process begins when ODSA detects an operational or logistics need, which is defined as a deficiency, formalized in a specific document (Operational Need—Necessidade Operacional), which can only be met through the provision of a new system or equipment or modification of an existing one. The operational need may also be due to a technological innovation that allows a new mission that will boost the efficiency of existing mission, a market opportunity for replacement of a device/obsolete system or an economic opportunity (Francelino et al. 2015).

The Coordinating Commission for Combat Aircraft (COPAC) was created in 1981 to manage the AM-X Program, so that the program's learning impacts shaped its conduct and its subsequent performance. The COPAC is the military organization responsible for coordinating the development and acquisition of combat aircraft. It is a specific body dedicated to managing the acquisition of complex systems through a contract management structure (Brazil 2010). The creation of COPAC made possible to establish the guidelines

for the management of the AM-X Program and allowed to extend this systematic to other programs and fields of the Brazilian Aeronautics Command through the creation of DCA 400-6 (Francelino et al. 2015).

Embraer is the prime contractor of Military Aircraft Acquisition Programs of Brazilian Aeronautics Command, the contracting has been carried out through Waiver of Bidding (Dispensa de Licitação) or Ineligibility of Bidding (Inexigibilidade de Licitação), based on Articles 24 and 25 of Brazil (1993), this Law regulates the public acquisitions in Brazil. The AM-X Program did not fit into this regulation because it was a joint purchase program between two countries. In general, COMAER contracts Embraer directly for the development of the aircraft, as in cases of AL-X and KC-390. When contracting the development of the aircraft, the Brazilian State is indirectly financing the Research and Development of the firm through technological orders. The next step is the hiring of the firm for the serial production of the aircraft. Complementary contracts are also made for the purchase of equipment utilized in the aircraft and aircraft support. The entire resource is centralized at Embraer, which has autonomy to choose its domestic and international suppliers, although COMAER has veto power over any supplier if it is of interest.

In terms of general lessons of Defense Programs, there were no aggregate and systematic data for all programs. The documents are very extensive and we do not have permission to address all issues. The focus of our data collection is the technological development promoted by Defense Programs, as well as about the impacts they have promoted in Embraer's trajectory and in other firms. In addition, information was collected through fieldwork at different times, performing interviews with specialists and managers of Embraer, Military Organizations, and academic researchers.

Even so, it was possible to observe an evolution in many aspects related to the management of the programs and the way of COMAER to encourage the development of the national industry. In the AM-X Program, COMAER acquired directly from abroad other lots of equipment, kits, and accessories for government aircraft supply (Government Furnished Equipment: refer to the purchase of general equipment, avionics, and accessories), according to a subcontracting scheme called Frame Contract. In other programs, COMAER has changed this way of acquiring equipment and accessories abroad. Throughout the AM-X Program, the experience demonstrated the need to have a firm qualified to verify the requirements of the product, such as Embraer Aviation International, a subsidiary of the Brazilian firm Embraer, based in Le Bourget (France), for the acquisition of supplies produced in European countries and in Israel; and Embraer Services Incorporated, another subsidiary of Embraer, with headquarters in Dallas, TX, for the procurement of supplies produced in the USA and Canada. The centralization of the purchase of equipment at Embraer facilitated the conduct of the contracts for COMAER, although it implies more autonomy to Embraer in the definition of its international partners (Francelino 2016).

The way of COMAER sought to stimulate national industry has also changed over the course of the programs. In the AM-X Program, Embraer was in charge of coordinating the Complementary Industrialization Program (Programa de Industrialização Complementar; PIC), an industrial capability program of COMAER which aimed to promote the industrial capability of Brazilian aeronautical firms for the development of AM-X fighter, in order to generate alternative sources of supply in the future. At the end of the program, national firms would be able to develop in technological and human terms, giving to Brazil a greater independence in the

production of aeronautical equipment and in its logistical support. The PIC led the development of Eleb (Embraer’s landing gear segment), Aerelectronics (Ael Systems—avionics) and Celma (GE Aviation—engines). The fact that Ael Sistemas and Celma were acquired by multinational firms does not invalidate the process of technological capabilities accumulation generated by the State in the AM-X Programs and other Programs (Francelino 2016).

In the programs after AM-X, the Offset Policy (Brazil 2005) was developed and deepened. The concept of Offset significantly altered the rationality of COMAER’s acquisitions abroad. Issues related to the transfer of technology from an external supplier to a firm or institution of science and technology located in Brazil have determined which firm will be chosen for the external purchase. Much more than the product itself, Brazil is interested in absorbing the technology so that in the future it can produce the same product or another with the technology that has been absorbed. However the widespread requirement of Offset does not contribute to the development of the industry if there is no complete planning for this development, it is necessary a strategic vision about long-term sustainability (Francelino 2016).

We also noted that COMAER has evolved in its complex contract management structure. In the AL-X Program, a high refinement was observed in the contractual part, the active participation of COMAER in all phases of the project was remarkable, especially in the development phase. The structures for monitoring and control of contracts were also improved through the managers responsible for each area.

All possibilities were exhausted in the contracts, putting strong pressure on Embraer. Several points about Defense Programs can be addressed; however, they do not fit to the scope of this article.

4.3 The impacts of Defense Programs on Embraer’s technological path

For each technological function analyzed, it was investigated if the participation of Embraer in Defense Programs led to the development of its technical, sustaining, and organizational technological capabilities. The evidence presents a consensus in the literature (Cabral 1992; Cassiolato et al. 2002; Marques and Oliveira 2009) and among industry experts (interviews with the founder Ozires Silva, and in Embraer, Eleb, AEL Systems, COPAC, IFI), about the importance of the AM-X Program for the development of the Brazilian aeronautics industry. This was a joint program between Brazil and Italy, in the beginning of the 1980s. Embraer was responsible for the production of the wings (29.7 per cent), Aeritalia was responsible for the production of the central fuselage (46.5 per cent) and Aermacchi for the super fuselage (23.8 per cent). In addition, Embraer participated actively in the development of the Brazilian Version. The impacts were categorized in the Product Development Function, within the subcategory of system architecture development and Manufacturing Engineering Function (Processes and Equipment). Thus, the AM-X Program allowed the development of frontier technology capabilities at Embraer, which were very

Table 3. Technical impacts of the AM-X and AL-X Programs on Embraer’s technological path.

Intrinsic Nature of the Function	EMITeC Technological Functions	Subcategories	AM-X	AL-X
Technical	Product Development	System Architecture Development	The development of the "Brazilian Version", AM-X aircraft with Brazilian specificities. The development and manufacturing of 30% of the aircraft, which means the wings. Introduction of CAD-CAM (Computer Aided Design-Computer Aided Manufacturing). The manufacturing under license of the landing gear (EDE).	No technological leap.
		Avionics	Digital transmission system: revolution on the instruments on board. At the beginning of the production of Brasilia, there were 10 people working in the area, with the AM-X that number increased to 60 specialists, many of whom were trained in Italy and worked directly in the program abroad.	Incorporation of current technology for avionics (embedded electronics), armament and sensors. Control, update and maintenance of the operational software. Autonomy for the integration of new systems and sensors, as well as local logistical support. Advanced capabilities for the integration of cutting-edge systems.
		Flight Controls Flight Test	The first contact with Fly-by-Wire System. AM-X aircraft needed sophisticated tests (inertial navigation system with accuracy check and photographic reconnaissance system), flight quality tests (stability and control) and performance with dynamic maneuvers (calculation of aerodynamic parameters in flight maneuvers). Increased the specialization of labor.	No technological leap. No technological leap.
		Integration	Partnership with Italian firms (Aeritalia and Aermacchi).	Integration of the aircraft. Integration capability of state-of-the-art in avionics from Elbit.

Source: Documentary research and fieldwork. (-) We did not find information about this function.

Table 4. Technical and sustaining impacts of the AM-X and AL-X programs on Embraer's technological path.

Intrinsic Nature of the Function	EMITeC Technological Functions	Subcategories	AM-X	AL-X
Technical	Manufacturing Engineering (Processes and Equipment)		Router Trumpf: digitally controlled equipment, best arrangement of the different parts for cutting the whole plate. Grantry's with five axles programmed by CAD-CAM, complex shapes and reduce tolerances. Manufacturing the wings of AM-X.	No technological leap.
Sustaining	Management Technological Capabilities Accumulation		The manufacturing of 30% of the aircraft, which means the wings. Embraer's employees were sent to Italy to receive technical qualification. The first contact with Fly-by-Wire System. The manufacturing under license of the landing gear (EDE).	Integration capability of state-of-the-art in avionics from Elbit (Offset).
	Diversification – Capabilities for Global Operation and in Other Markets	-		This case represented innovation in the marketing area, reaching sales success all over the world. This is an internationally recognized aircraft.
	Formal Networks of Development		Partnership with Italian firms (Aeritalia and Aermacchi). The manufacturing under license of the landing gear (EDE).	Risk partnerships.

Source: Documentary research and fieldwork. (-) We did not find information about this function.

Table 5. Organizational impacts of the AM-X and AL-X programs on Embraer's technological path.

Intrinsic nature of function	EMITeC Technological Functions	Subcategories	AM-X	AL-X
Organizational	Innovation Management		-	Advanced capabilities to search new markets.
	Supply Chain Management.		-	Advanced capabilities to manage the suppliers. Integrative firm.
	Project Management		-	-

Source: Documentary research and fieldwork. (-) We did not find information about this function.

relevant to its evolution in commercial aviation. Tables 3–5 summarize the results of the evaluation of the impacts.

The partnership with Italy also promoted impacts in other areas of the Product Development Function, such as in avionics, flight controls, flight test, and integration. For example, a technology jump was observed with the replacement of electronic equipment by integrated electronics; the introduction of the Fly-by-Wire systems in AM-X boosted the introduction of integrated avionics in Embraer; the development of new flight tests; the use of computer-aided design - computer-aided manufacturing (CAD-CAM). In the Manufacturing Engineering Function (Processes and Equipment), the impacts were also categorized due the introduction of new equipment (Router Trumpf, digitally controlled equipment, and Grantry with five axles programmed by CAD-CAM), as well as the impacts from changes in the arrangement of the different parts for cutting the whole plate; complex shapes; and from the reduction of tolerances (Cabral 1992, 1987).

During the internship at the COPAC, the Memorandums of Understanding between Brazil and Italy and the main contracts of the AM-X Program were analyzed. It was verified that the AM-X Program's Architecture allowed the creation of significant knowledge flows from the Italian firms (Aermacchi and Aeritalia) to the

Brazilian Firm, since Embraer actively participated in the development phase of the Brazilian Version. As a result, very significant impacts were caused on the Management Technological Capabilities Accumulation Function and the Networks of Formal Development Function, especially regarding the acquisition of external knowledge.

In addition, the firm Eleb came from the Embraer Equipment Division (Embraer Regional Jetliners; EDE), which was established in 1984 to manufacture the AM-X landing gear under license, internalizing the know-how of the landing gear system and hydraulic components in Brazil, with impacts in the subcategory system architecture development of the Product Development Function. Other impacts were perceived in the Management Technological Capabilities Accumulation Function related to human resources training due to the immersion of Embraer's workforce in Italy.

AM-X Program's architecture also contributed to the technological development of the selected firms through the Complementary Industrialization Program [Programa de Industrialização Complementar (PIC)]. Specialists considered PIC as the only comprehensive Capability Program of the Brazilian Aeronautics Command, which caused large impacts on the reality of aeronautics firms, since it supported the development of important technological capabilities in Brazil, like in the avionics area at Aeroeletronica, engine area at

Celma, and landing gear area at Eleb. In fact, the PIC was remarkable to the development of the industry in the following years. The firms acquired the technological capability and, thus, the right to produce equipment in Brazil under license from foreign suppliers. Embraer managed this program, guiding the development of technological capabilities of firms towards benefiting the Brazilian industry as a whole.

In the 1990s, COMAER contracted Embraer for the development of the Super Tucano (AL-X). This is a good example of COMAER's ability to develop high-level aircraft requirements. However, considering Embraer's technical capability, there was no technological leap. The firm already had internal knowledge (technical and organizational) at that time to conduct all phases of the project, and to accomplish the serial production. Regardless, the AL-X was an aircraft entirely developed by Embraer, specialists

considered it as a case of innovation in the marketing area of the firm, and it reached sales success all over the world. The international recognition of the aircraft places Embraer as a firm with competitive levels of technological capability in the global aeronautical market. The impacts occurred on the Diversification Function—Capabilities for Global Operation and in Other Markets, especially on the firm's ability to expand its sales abroad. In this Program, the Offset Plan for the transfer of knowledge (Commercial, Industrial, and Technological Compensation Agreements) became a practice.³ Tables 3–5 summarize the results of the evaluation of the impacts.

In the 1990s, COMAER also contracted Embraer for the modernization of F5 Aircrafts (F5-BR); which were bought from the USA and Jordan, without the navigation and attack systems that would meet the needs of the Brazilian Air Force, and with an obsolete avionics system. Embraer was responsible for providing

Table 6. Technical impacts of the modernized AM-X, F5-BR, and KC-390 Programs on Embraer's technological path.

Intrinsic Nature of the Function	EMITeC Technological Functions	Subcategories	Modernized AM-X	F5-BR	KC-390
Technical	Product Development	System Architecture Development	-	-	Entire development of the aircraft. Development and production of cutting-edge landing gear (84 tons).
		Avionics	Incorporation of current technology for avionics (embedded electronics), armament and sensors. Control, update and maintenance of the operational software. Autonomy for the integration of new systems and sensors, as well as local logistical support. Advanced capabilities for the integration of cutting-edge systems.	Incorporation of current technology for avionics (embedded electronics), armament and sensors. Control, update and maintenance of the operational software. Autonomy for the integration of new systems and sensors, as well as local logistical support. Advanced capabilities for the integration of cutting-edge systems.	Advanced integration capabilities in avionics.
		Flight Controls	-	-	The development of the whole Fly-by-Wire System, unprecedented at Embraer.
		Flight Test	-	-	Aircraft and landing gear - new test paradigm. The firm built a new 17-meter-high free-fall machine to reproduce the landing conditions. The tests also include equipment exposure cycles for consecutive hours at low and high temperatures, which simulate ultra-severe weather conditions found in the tropics. The actuators also simulate loads and wear that are equivalent to 30 years of useful life.
		Integration	Integration capability of state-of-the-art in avionics from Elbit.	Integration capability of state-of-the-art in avionics from Elbit.	Integration of the aircraft. Greater integration between the mission system and the basic avionics system.

Source: Documentary research and fieldwork. (-) We did not find information about this function.

Table 7. Technical and sustaining impacts of the modernized AM-X, F5-BR, and KC-390 programs on Embraer's technological path.

Intrinsic Nature of the Function	EMITeC Technological Functions	Subcategories	Modernized AM-X	F5-BR	KC-390
Technical	Manufacturing Engineering (Processes and Equipment)	-	-	-	Border manufacture in Portugal for machining very large parts, acquisition of 65% of the shares of the firm Ogma.
Sustaining	Management Technological Capabilities Accumulation		Integration capability of state-of-the-art in avionics from Elbit (Offset).	Integration capability of state-of-the-art in avionics from Elbit (Offset).	Engineering teams working in specific areas. Continuous endogenous knowledge acquisition activities to solve problems.
	Diversification – Capabilities for Global Operation and in Other Markets	-		Upgrade systems of aircrafts with high degree of commonality with F5-BR, such as AL-X and the modernized AM-X.	There are already several orders abroad. Great sales potential all over the world.
	Formal Networks of Development	-		Integration capability of state-of-the-art in avionics from Elbit (Offset).	Risk partnerships with international firms. Technical partnerships with Brazilian firms in the machining and engineering segments.

Source: Documentary research and fieldwork. (-) We did not find information about this function.

Table 8. Organizational impacts of the modernized AM-X, F5-BR, and KC-390 programs on Embraer's technological path.

Intrinsic nature of function	EMITeC Technological Functions	Subcategories	Modernized AM-X	F5-BR	KC-390
Organizational	Innovation Management		-	-	Advanced capabilities in Research and Development during the development phase of the Program, engineering teams working in specific areas. The development of a unique aircraft, the development of cutting-edge landing gear and the development of the whole Fly-By-Wire System for the first time.
	Supply Chain Management.		-	-	Advanced capabilities to manage the suppliers. Integrative firm.
	Project Management		-	-	-

Source: Documentary research and fieldwork. (-) We did not find information about this function.

specialized technical support to COMAER in the process of selecting firms to supply modernized equipment and avionics software. The strategic policy of COMAER was oriented by internalizing the maximum of manufacturing and maintenance technology, in accordance to its Offset Policy. In 1998, Elbit (Israel), GEC-Marconi (England), IAI (Israel), and SAGEM (France) offered proposals. Elbit was selected to supply modernized equipment, logistic support, materials and services, test equipment, and upgraded systems for F5 aircrafts and other aircrafts with high degree of commonality, such as the AL-X and the modernized AM-X. COMAER's Offset Policy established that Elbit had to acquire shares of a Brazilian firm. Elbit acquired Aeroelectronica, a Brazilian avionics firm, and renamed it as AEL Systems. According to interviews, Elbit had no knowledge of the great potential of human and technological resources of the firm. During the years following the acquisition, foreign executives participated daily in the firm. This acquisition led to new business overseas, especially in France, supported by Brazilian teams.

Embraer was the prime contractor of all F5 contracts, considering COMAER's strategy of establishing the technological capabilities to maintain updated and modernized systems in Brazil, especially the operational software of the aircraft and the integration of new sensors and armaments, without external dependence. The F5 Program allowed Embraer to acquire the integration capability of state-of-the-art in avionics from Elbit. Such contracts caused significant impacts on the Management Technological Capabilities Accumulation Function, and on the Formal Networks of Development Function, mainly on the activities related to the acquisition of external knowledge and formal contracts with other firms, which ensured a frontier knowledge flow for Embraer in avionics, which is an extremely important area. Tables 6 and 7 summarize the results of the evaluation of the impacts.

Currently, the most important Defense Program is the KC-390 Program. Embraer developed the military aircraft entirely, following the engineering requirements of COMAER. The development contract was signed in 2009. The KC-390 is the largest aircraft

developed by Embraer and unites in a single plan the capacity to attend numerous missions, such as search and rescue, transportation, refueling, launching cargo and paratroopers, medical evacuation, fighting forest fires, among others. The KC-390 is a large size high-wing, jet-powered aircraft, capable of landing on unpaved and unprepared runways, developed using cutting-edge technologies from several areas. Embraer is responsible for the development and integration of the aircraft, and the production of several items and products. The development, engineering, and integration of the aircraft by Embraer translate, according to the interviewees, the great effort of local content of this aircraft. The integration effort involves international partners and a large number of equipment and system suppliers, under the technical coordination of Embraer. The firm also subcontracted others Brazilian firms, such as Akaer, to detail the engineering design of some structures, creating overflows of this Program within the country. The KC-390 Program also impacted machining Brazilian firms (small- and medium-sized), but this is not the focus of this article. Tables 6–8 summarize the results of the evaluation of the impacts.

Regarding the innovative capabilities developed, Embraer is responsible for the entire development of the Fly-by-Wire system for the KC-390 aircraft, which did not occur in previous programs. The size of the aircraft was also a challenge, since it reflected changes in the structural architecture and in the tests, creating new capabilities in the organizational base of the firm. When compared to previous programs, the KC-390 requires a deeper integration between the mission and avionics systems. Eleb, the landing gear firm of Embraer, developed a landing gear that supports 84 tons. The process of designing, development, testing, and manufacturing of the KC-390's main and auxiliary landing gear set took five years. Such achievement constitutes an expressive technological leap for the segment, mainly when it is known that the landing gear of the Embraer Regional Jetliners 145 family supports 24 tons. The KC-390 Program also changed the paradigm of tests in Embraer.

According to the interviewees, this program raised the firm to a new technological level and without it, the firm would need to rely on partnership projects with universities and institutes to achieve the

same level of technological development and quality and probably spending decades for such. Finally, manufacturing solutions to build the KC-390 were different from the usual solutions, which also generate specific capabilities in Embraer and its Brazilian subcontractors. The degree of automation is higher for the production of large aircrafts. In this sense, the main technological impacts of the KC-390 Program on the technological path of Embraer were perceived expressively on the Technical Function categorized as Product Development, for example, the development and integration of the KC-390, the development of the landing gear, an advanced integration capabilities in avionics and the development of the whole Fly-by-Wire system. These impacts also reflected on the Organizational Functions, especially on Innovation Function. The main impacts were also observed on Sustaining Functions, due to the continuous efforts of the firm to solve problems and interact with its partners and subcontractors.

Thus, from the analysis of the main Brazilian Defense Acquisition Programs implemented in the last forty years in the aeronautics industry, it is evident that the AM-X and KC-390 Programs generated a set of impacts that largely affected most of the functions investigated, highlighting the relevance of these programs to the technological path of the firm. The tables presented (Tables 3, 4, 5, 6, 7 and 8). list the capabilities generated at Embraer from the participation in the Defense Acquisition Programs using the EMITeC functions.

5. Discussion

The EMITeC Model was developed to evaluate the impacts of public programs on Brazilian aeronautics firms, which have participated in several Military Aircraft Programs since the 1980s until nowadays. For Embraer, EMITeC was adapted to evaluate the main aspects of Embraer's technological capabilities accumulation, which could be attributed to the implementation of Brazilian PPI. EMITeC technological functions are grouped according their technical, organizational, and sustaining nature and divided into capabilities that the firm needs to master to evolve over the years. EMITeC categories allow a

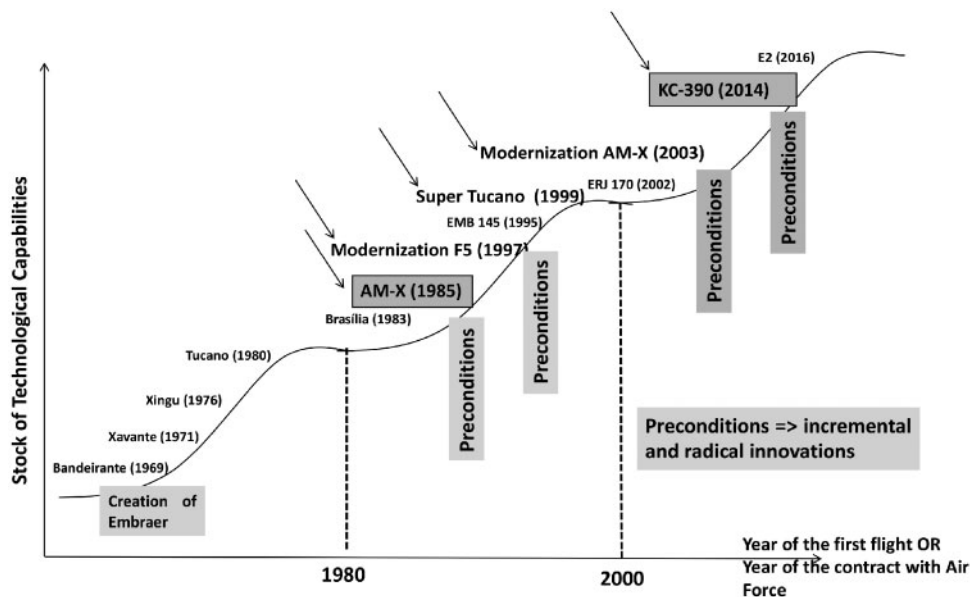


Figure 1. Embraer's technological path through its aircraft models. Own elaboration based on research and fieldwork.

general identification of the level of coverage of industrial policies and shows which technological functions could be impacted by the purchase policy of the Brazilian Aeronautics Command.

In general, Embraer's technological capabilities accumulation results from the continuous development of aircrafts in its programs over time, in an ascending sequence, which generates continuity in the development of knowledge (Fig. 1). Each Program from Embraer represents a step forward for the firm throughout its history. The technological accumulation path requires directly contracting Embraer for the development of aircrafts (Source: Interviews). For a firm like Embraer to remain competitive, it needs to have an area dedicated to the development of precompetitive technologies, which usually goes from Technology Readiness Level (TRL) 2 to TRL 4 or 5, depending on the technology (Mankins 2009). This area in Embraer is called Technological Development (Desenvolvimento Tecnológico; DT). The maturation supplement, TRL 6 to 9, is that it must be conducted by military programs.⁴ In this sense, we can argue that COMAER's Aircraft Acquisition Programs have been an important demand-side policy for the development of innovations in the firm. However, it must highlight that this research, although aware of, has disregarded the existence of externalities that flow from civil programs to the military programs.

Embraer, in the agreements with the Brazilian Aeronautics Command, focused its efforts on prioritizing the acquisition of knowledge for technologically relevant areas on the development of new aircrafts, especially to become the owner of technologies that would guarantee a competitive advantage over the years (Cassiolato et al. 2002; Chagas Jr et al. 2017). Considering the KC-390 Program, the public funding allowed the necessary maturation time to develop the whole Fly-by-Wire system and aircraft landing gear using cutting-edge technologies. This also allowed a shorter turn-around time for the launch of new products in commercial aviation, such as the recently launched E2 in 2016.

In Fig. 1, the stock of technological capabilities of Embraer for different models of aircraft (civil and military) is plotted against time on the horizontal axis. The development trajectory of a successful transition from one accumulated stock of technological capabilities to another will take the form of a set of S-curves (Christensen 2009). The technological capabilities are a stock variable, they comprise a reservoir of resources, which allows the firm to carry out both production and innovation activities to varying degrees (Figueiredo 2013).⁵ They could translate the state-of-art for the firm, not to the world, and include what Embraer really learned and accumulated in a period of time in an ascendance trajectory—Embraer's technological path.

The first curve S encompasses the firm's first programs, in which the firm learned how to carry out serial production of aircraft. Embraer was created in 1969 for the Bandeirante serial production, which was developed at Aeronautical Technical Center (Centro Técnico de Aeronáutica), currently, Departamento de Ciência e Tecnologia Aeroespacial (DCTA). The Bandeirante aircraft was developed in 1968 (two prototypes). It was done with techniques below the state-of-art. Nevertheless, such technological choice was considered adequate both to learn the basics of aeronautics manufacturing and to fulfill the logistic challenge of Brazil's national integration intended by COMAER. Thus, this first big public purchase of COMAER, which through the order of 80 aircrafts; brought about the launching of the industrial program of Embraer. In the same period, began the searching of a training aircraft for the equipment of Brazilian Air Force—Xavante. Aeromacchi was the Italian firm chosen for the licensing of the Xavante project for Embraer

(112 units orders), with several positive aspects regarding the technical assistance of the aircraft. These two initial contracts with COMAER, signed in May 1970, amounted to about \$1.2 billion, was a powerful initial push for a firm that had just begun (Silva 1998).

The second curve S encompasses the programs that provided significant technological leaps for Embraer, such as the Brasília civil program (Frischtak 1994) and the AM-X military program. Even though it was a civilian aircraft, Brasília was widely used by the Brazilian Air Force and was, therefore, the target of public acquisitions. In addition to the impacts of the AM-X Program that were mentioned in the previous section, which generate positive impacts in the development of the firm's civil programs, it is worth noting that much of the technological learning to deal with the turbofan propulsive system comes from the AM-X program. The coupling of this propulsive system with the aircraft is quite distinct from the turboprop propulsion system. Thus, based on this technological learning, Embraer achieved a good position in the regional aviation segment first with EMB 145, which created the conditions for the expansion of regional aviation, with platform 170/190; and then migrated to the programs of the executive aviation.

The third curve S represents Embraer's latest and most recent technological leap, promoted by the KC-390 Program. According to the interviewees, the entire development of the Fly-by-Wire system for the KC-390 aircraft, and the development of a landing gear that supports 84 tons provided the most important impacts in the latest E2 commercial program. For the first time in his history, Embraer united the technical and organizational capabilities for the entire development of the Fly-by-Wire system. The learning process of such achievement initiated with the first contact of Embraer with a Fly-by-Wire system that occurred in the AM-X Program. Subsequently, in the civil programs EMB 170/190/175/195, Embraer decided to develop Fly-by-Wire systems with a risky partnership with Honeywell (Chagas Jr et al. 2017), because it did not have complete dominion over the technology. Afterwards, the leap on technological capabilities provided by the KC-390 Program, allowed Embraer to launch the second generation of E2 with the full Fly-by-Wire system developed with internal capabilities of the firm (software). In the case of KC-390's landing gear, the process of designing, developing, testing, and manufacturing took five years inside the development phase of KC-390 Program. The interviewees emphasized that KC-390's landing gear is very high, which greatly facilitated the development and manufacturing of the E2 landing gear in a record time.

In this sense, it is argued that the Defense Programs, especially AM-X and KC-390, generated the technical, sustaining and organizational preconditions that allowed the firm develops incremental and radical innovations for the civil programs (commercial and executive). Thus, to the AM-X's turbofan propulsive system could be attributed the good positioning of Embraer in the commercial aviation segment with EMB 145, 170, 190, 175, 195. In addition, to the development of the Fly-by-Wire system and of the landing gear for the KC-390 could be credited the generation of an innovative aircraft E2 in a record time.

Thus, the results suggest that the Defense Programs of the Brazilian Aeronautics Command caused a great impact on the accumulation of technological capabilities of the leading firm, Embraer. This reinforces what Vertésy (2011) emphasized, that the Sectoral System of Innovation of the Brazilian Aeronautics Industry gravitates around Embraer. The impacts of Defense Programs on Embraer's path were perceived on the accumulation of technological capabilities, especially in Technical and Sustaining Functions, which partially explains the evolution of the maturity of Embraer. Defense

Programs have been essential for the development of new technological capabilities in the firm. The proposed Model (EMITeC) can be considered an effective evaluating tool of Defense Programs.

PPI is an industrial policy mechanism of the Brazilian Aeronautics Command and a central piece for the technological development of Embraer. Can Embraer's position in the international market be maintained, if there is no continuity on the implementation of new Defense Acquisition Programs capable of pulling the technological capability development of the firm? Considering the negotiation between Boeing and Embraer, these issues must be addressed.

6. Conclusion

This article sought to evaluate the impacts of Brazilian Defense Acquisition Programs (AM-X, AL-X, F5-BR, and KC-390 Programs) on Embraer's technological path, over the last forty years. This was done through an evaluation Model, in the form of a matrix called EMITeC, designed with the main technological functions of an aeronautics firm, such as Embraer, and capable of showing how technological capabilities evolve towards greater complexity. The use of EMITeC as an evaluation instrument of the impacts of Public Programs requires an iterative and interactive research design, such as in-depth fieldwork with documentary and bibliographical research.

This study concluded that Military Aircraft Acquisition Programs are important as industrial policy instruments to develop the aeronautical industry. They are levers for the technological development of the chosen firms. However, the evaluation of the impacts caused by those policy instruments has received little attention within the academic literature. Therefore, this study collaborated with the literature, identifying the impacts of Brazilian Defense Acquisition Programs, from the perspective of the technological capabilities accumulation path at firm level. In this sense, this article has brought elements that contribute for the understanding of the technological impacts of Military Aircraft Acquisition Programs on Embraer.

The evidence suggests that COMAER's Aircraft Acquisition Programs have been an important demand-side policy for the development of Embraer's innovations in several technological areas. The AM-X Program allowed the development of cutting-edge technological capabilities at Embraer, which were critical for its evolution. Especially, the acquisition of technical capabilities to develop and manufacture the wings for both versions of the aircraft, Brazilian and Italian; the use of CAD-CAM in product development; the acquisition of know-how of the landing gear systems and hydraulic components; the first contact with the Fly-by-Wire system; the development of new flight tests; numerical control equipment in manufacturing, etc. These new activities caused very significant impacts on the Sustaining Functions, such as the Management Technological Capabilities Accumulation Function, and the Networks of Formal Development Function, especially regarding the external acquisition of knowledge. The impacts are also observed, mainly, on Technical Functions, such as Product Development, the origin of technological evolution.

The AL-X Program was a case of innovation in the marketing area of Embraer, despite no technological leap. The firm already had internal knowledge (technical and organizational) to conduct all phases of the project and the serial production. We must highlight that the aircraft was entirely developed by Embraer, according to COMAER's requirements, and reached sales success all over the world, being an internationally recognized aircraft. The impacts occurred on the Diversification

Function—Capabilities for Global Operation and in Other Markets, especially on the firm's ability to expand its sales abroad.

The F5-BR Program allowed Embraer to acquire the integration capability of the state-of-the-art in avionics from Elbit. Embraer developed capabilities to maintain and update a modernized system, the operational software and the integration of new sensors and armaments, without external dependence, in all military aircrafts with high degree of commonality, such as the AL-X and the modernized AM-X. Such contracts caused significant impacts on Management Technological Capabilities Accumulation Function and Formal Networks of Development Function, mainly on the activities related to the acquisition of external knowledge and formal contracts with other firms, which ensured a frontier knowledge flow for Embraer in an extremely important area.

The KC-390 Program allowed Embraer the entire development of the KC-390, according to COMAER's engineering requirements. This case represented innovation for the firm in several areas; it is the largest aircraft developed by Embraer. The development, engineering, and integration of the KC-390 by Embraer translate, according to the interviewees, the great effort of local content of this aircraft. This Program also allowed the development of the whole Fly-by-Wire system of the aircraft, which was not done in previous programs; and the development of landing gear that supports 84 tons, an expressive technological leap for the segment. The impacts were perceived mainly on Technical Functions, like Product Development, on Organizational Functions, especially on Innovation Management, and on Sustaining Functions, due to the continuous efforts of the firm to solve problems and to interact with partners and subcontractors.

Thus, the results suggest that the Defense Programs of the Brazilian Aeronautics Command have had a great impact on the accumulation of technological capabilities of Embraer, especially in its Technical and Sustaining Functions, this partially explains the evolution of the maturity of Embraer. This means that Defense Programs have been essential for the development of new technological capabilities at Embraer. Furthermore, there is a very mature relationship between COMAER and Embraer, which allow the development and manufacturing of competitive aircraft in the international market, based on the engineering requirements established by COMAER. The application of EMITeC categories to Embraer case shows a new way of analyzing the impacts of Defense Programs at firm level, in terms of the accumulation of technological capabilities relevant for the evolution of the firm and industry.

Among the main contributions are:

1. The development of a new approach for the evaluation of the impacts of Defense Programs, through the identification and analysis of such impacts at firm level, in terms of technological capabilities accumulation. In fact, this approach can be considered a novelty in the literature review.
2. The results presented in a formal way, EMITeC categories, allow the visualization of the technological capabilities developed at Embraer and supported by public programs.
3. The analyses of the last forty years of Military Aircraft Acquisition Programs of the Brazilian Aeronautics Command.

Notes

1. <https://www.wsj.com/articles/boeing-tries-to-overcome-brazils-resistance-to-embraer-takeover-1515174634> (accessed 27 Mar 2018).
2. The Brazilian Air Force is the armed wing of the Brazilian Aeronautics Command (COMAER).

3. COMAER's Offset Policy: '... any and all compensatory practice agreed upon by the parties as a condition for the importation of goods and services with the intention of generating industrial, technological, and commercial benefits' (Brazil 2005: 10). The compensation arrangements are a form of transferring technology: technical assistance, research and development, training and other activities that represent a qualitative increase in the country's technological level. As a rule of the Brazilian Ministry of Defense, it has been established that import contracts involving amounts in excess of 5 million dollars or equivalent in another currency must necessarily include compensation clauses, in the case of a single purchase or a cumulative purchase with the same supplier.
4. With the Joint Venture Boeing (majority)—Embraer there is a new and important stakeholder that can interfere in this organizational learning process, eventually redefining technology development priorities. As Boeing has more advanced technologies, one can imagine a scenario where DT only complements the technology developments that it already has, or even a scenario in which this complement is made by Boeing itself, interrupting the flow of organizational learning which migrates from military technologies to civilian segments.
5. Transcription of the argument of Professor Paulo N. Figueiredo (Figueiredo 2002), in the Author's Qualification Committee, at Aeronautics Institute of Technology, São José dos Campos, Brazil, 12 December 2013.

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