DOI: 10.14267/phd.2016013

Dániel Vértesy

Cycles of Economic and Technological Change in Latecomer Aerospace Industries

DOI: 10.14267/phd.2016013

Department of World Economy

Supervisor: Dr. András Blahó, CSc

DOI: 10.14267/phd.2016013

Corvinus University of Budapest

International Relations Multidisciplinary Doctoral School

Cycles of Economic and Technological Change in Latecomer Aerospace Industries

Ph.D. Dissertation

Vértesy Dániel

Budapest

2015

DOI: 10.14267/phd.2016013

DOI: 10.14267/phd.2016013

Table of Contents

List of Tables 7

List of Figures 8

CHAPTER 1: INTRODUCTION 11

1.1 Change as co-evolution 11

1.2 Research Design 17

CHAPTER 2: THE TWO WAVES OF INTERNATIONALIZATION IN THE GLOBAL AIRCRAFT INDUSTRY 25

2.1 Introduction 25

2.2 The state of commercial aircraft manufacturing and its main development trends 26

2.3 The limits to internationalization 47

2.4 Two waves of internationalization 49

2.5 Conclusion 53

CHAPTER 3: LITERATURE ON CATCH-UP, SCHUMPETERIAN DYNAMICS AND INNOVATION 56

3.1 Introduction 56

3.2 Latecomer advantages and how to benefit from them 57

3.3 Technological capabilities 61

3.4 Systems of innovation 67

3.5 Previous studies on innovation and growth in latecomer aerospace industries 74

3.6 Technological change and industrial dynamics in the global aircraft industry of the jet age 77

CHAPTER 4: EXPLAINING SUCCESS AND FAILURE OF CATCH-UP IN AIRCRAFT MANUFACTURING 91

4.1 A Theoretical Framework on Innovation Systems Dynamics 91

4.2 BRAZIL 101

4.3 CHINA: Slowly transforming, parallel Systems 125

4.4 SINGAPORE 144

4.5 ARGENTINA: The case of a languishing aerospace innovation system 165

4.6 INDONESIA 189

CHAPTER 5: UNDERSTANDING FIRM-LEVEL DYNAMICS: SUCCESSIVE CHANGES IN LEADERSHIP IN THE REGIONAL JET INDUSTRY 210

5.1 Introduction 210

5.2 The regional jet industry and the record of leadership changes 211

5.3 Theoretical Framework: A dynamic perspective on sectoral innovation systems 216

5.4 Bombardier’s leadership in the 50-seat segment (1995-2005) 224

5.5 Embraer’s leadership in the 70-120-seat segment (2005 –) 231

5.6 Conclusions 237

DOI: 10.14267/phd.2016013

CHAPTER 6: CONCLUSIONS: SCHUMPETERIAN DYNAMICS IN THE AIRCRAFT INDUSTRY 246

6.1 The three types of cycles and the evolutionary challenge 246

6.2 Riding the second wave of internationalization 247

6.3 Success and failure in catch-up 248

6.4 Leadership changes 264

6.5 Cautionary remarks for companies and governments with aerospace industry ambitions in Central and Eastern Europe 272

6.6 Aircraft production, innovation and the changing global balance of power 276

BIBLIOGRAPHY 279

List of related publications by the author 294

DOI: 10.14267/phd.2016013

List of Tables

Table 1.1 The elements of Aerospace Manufacturing in the U.S. Annual Survey of Manufactures (2010) 21
Table 1.2 A schematic overview of the research design (research questions and applied methodology) 23
Table 2.1 Demand Forecast for New Aircraft by Major Manufacturers 29
Table 2.2 Key indicators on the evolution of the aerospace industry, 1960-2010 31
Table 2.3 Characteristics of the two waves of internationalization in the aircraft industry 53
Table 3.1 Overview of major new-to-the-world innovations in civilian aircraft 80
Table 4.1 First series production of airplanes in Brazil, 1936-51 103
Table 4.2 The main products of Embraer 120
Table 4.3 Main indicators on the national innovation system of Singapore, 1990-2009 146
Table 4.4 Major local assembly and upgrading projects at ST Aerospace (1974-2007) 150
Table 4.5 Growth of passenger and cargo air traffic in Singapore, 1973-2006 150
Table 4.6 General Statistics of the Singapore Aircraft Industry (1977-2007) 155
Table 4.7 Argentina's Aerospace production in comparison, selected years 165
Table 4.8 Name and size changes of the aircraft manufacturing plant of Córdoba 166
Table 4.9 Serial Aircraft Production in Argentina 168
Table 4.10 Stock of aeronautical engineers in Argentina (1950-2007) 170
Table 4.11 Military aircraft import to Argentina (1950-2009) 176
Table 4.12 Main features of the Guarani II in comparative perspective 178
Table 4.13 Key financial data of IPTN, 1976-89, compared with the first years of Embraer 192
Table 4.14 Number of aircraft and helicopters delivered by IPTN (1975-98) 193
Table 4.15 Key performance characteristics of IPTN's and competing aircraft 196
Table 4.16 IPTN's machinery for aircraft manufacturing 202
Table 5.1 Technological and market performance of leading regional jets 239
Table 5.2 Key drivers of leadership change: preconditions, windows of opportunity and leading products 240

DOI: 10.14267/phd.2016013

List of Figures

Figure 1.1 The global supply chain in the case of the Boeing 787 "Dreamliner" 16

Figure 2.1 Evolution of the Aerospace Industry, 1970-2010 32

Figure 2.2 Total and commercial segment sales value for the global Top 20 aerospace producers, 2012 35

Figure 2.3 Evolution of commercial aircraft exports by selected world regions 39

Figure 2.4 The 10 largest aircraft exporters (1970-2012) and their market share (in 2012, %) 41

Figure 2.5 The 10 largest aerospace producer countries by value added, 1970-2010 42

Figure 2.6 Trends in the global distribution of Aerospace jobs, 1980-2010 43

Figure 2.7 Aircraft imports of emerging economies 44

Figure 2.8 Balance of trade in aircraft for selected emerging economies 45

Figure 2.9 Share of intermediate goods in aircraft exports of selected countries 46

Figure 2.10 Evidence of latecomer entry through the supply chain 47

Figure 2.11 Evolution of Business R&D expenditures by aerospace manufacturers in selected economies 49

Figure 4.1 Performance in a given innovation system 94

Figure 4.2. Radical Change of the Sectoral Innovation System: Transition 94

Figure 4.3. Interrupted Innovation 96

Figure 4.4. Interruption followed by successful transition to a new innovation system 97

Figure 4.5. A learning trajectory: interruption and successful transition 98

Figure 4.6 The evolution of aircraft production in Brazil, 1936-2010 105

Figure 4.7 Embraer's sales, exports and number of employees, 1970-2007 112

Figure 4.8 Trends of catch-up: aerospace VA of BRA, CHN and IND compared to the USA, 1970-2007 (%) 113

Figure 4.9 R&D Expenditure and R&D intensity of Embraer, 1983-2007 115

Figure 4.10 Number of patents in the field of aerospace granted by year of application (1974-2007) 116

Figure 4.12 The interrupted trajectory of the development of the Brazilian aerospace industry (1930s-2007) 123

Figure 4.13 Estimated Chinese Jet Fighter Production, 1960–1995 128

Figure 4.14 Military aircraft export from China, 1960-2008 128

Figure 4.15 Export of Chinese Military and Commercial Aircraft, 1955-2008 132

Figure 4.16 R&D Expenditure and R&D per Sales in Chinese Aerospace Industry, 1995-2007 133

Figure 4.17 Patent statistics of aerospace enterprises 134

Figure 4.18 Employment and Labour Productivity Growth in the Chinese Aerospace Industry, 1995-2007 135

Figure 4.19 Interruptions and transition in the Chinese aircraft innovation system 142

Figure 4.20 Gross Output, Value Added and Employment in the Singapore Aerospace Industry, 1977-2007 151

Figure 4.21 Maintenance, repair and overhaul revenues of ST Aerospace and SIA Engineering, 1996-2008 158

Figure 4.22 The National Innovation System of Singapore - R&D Expenditures, 1981-2009 159

Figure 4.23 Radical innovation system change in Singapore's sectoral innovation system in Aerospace 162

Figure 4.24 Comparison of annual production of commuter-size aircraft by FMA, Embraer and Nurtanio (in first 20 years of production) 179

Figure 4.25 Argentine Military Expenditures, in millions of constant (1970) Australs (1969-1987) 180

Figure 4.26 The Emergence of the Argentine Aerospace innovation system 186

DOI: 10.14267/phd.2016013

Figure 4.27 Aircraft production cycles in Indonesia (1975-2006) 195
Figure 4.28 Comparison of cumulative aircraft production in Spain and Indonesia 197
Figure 4.29 Emergence of the Indonesian aerospace innovation system 207
Figure 5.1 Average annual crude oil prices in real terms, 1970-2011 212
Figure 5.2 Number and types of regional jets delivered by BAe (left panel) and Fokker (right) 214
Figure 5.3 Regional Jet Deliveries, 3-year moving average, 1980-2010 215
Figure 5.4 Diagram of theoretical framework 222
Figure 5.5 Number and types of regional jets delivered by Bombardier in contrast with BAe and Fokker 227
Figure 5.6 Size and type competition in the regional market 227
Figure 5.7 Number and types of annual regional jet deliveries by Embraer in contrast with Bombardier 233
Figure 6.1 Parallel evolution of the emerging aircraft industries in 4 selected countries 250
Figure 6.2 Top emerging intermediate exporters (with share in world intermediate exports, %) 250
Figure 6.3 A duopoly change reflected in the cumulative number of regional jets delivered 271

Acknowledgements

I would like to thank my supervisor, András Blahó for his continued support, and to Mihály Simai, for convincing me to finish this project. I would also like to express my thanks for the useful comments and helpful suggestions to I received on the evolving versions of parts of this thesis (and the draft), particularly from Adam Szirmai, as well as Martin Bell, Sören Eriksson, Péter Gál, Keun Lee, Csaba Makó, Franco Malerba, Sunil Mani, Jorge Niosi, Andrea Szalavetz, Balázs Szent-Iványi, and many other whose contribution I may have failed to mention here. A significant part of this research was conducted at UNU-MERIT, and I am grateful for their support; I would also express thanks to all those supporting my field research in Brazil and China. I would also like to thank the readiness from the Doctoral Office of Corvinus University to help with administrative issues. Last but not least, I would like to thank my family for all their support and patience.

DOI: 10.14267/phd.2016013

Chapter 1: Introduction

1.1 Change as co-evolution

This dissertation is about long-term changes in the world economy, as seen from the perspective of a particular industry. ‘Change’ simply means becoming different, but it is a rather complex phenomenon, given the differences in the degrees of difference and in the way of becoming different. It can refer to fundamental or marginal transformations, undisputed to observers or hard to distinguish from the state of stability, and can be of radical or gradual nature. The convolution is certainly amplified if one is to identify change in a complex system such as the world economy.

Over the past half a century, we have witnessed multitude of global transformations (Simai, 2001). To highlight a few: some of the developing countries transformed into advanced industrialized ones; accelerated economic growth and a significant improvement of living standards in newly industrializing economies of Southeast Asia and ‘BRIC’ countries, most of all China. New information and communication technologies (ICT) allowed an unprecedented level of interconnectedness and growing interdependence between economies as the process of globalization unfolded. The different parts and components of today’s products have often traveled thousands of miles by the time they reach their consumers. The transformations have far-reaching social and political consequences; from changing the nature of international social interactions to shifting the world order established after the end of the Cold War. Regional economic and military powers have emerged, striving for increased political influence. Some governments don’t spare funding from military-industry complexes, even to the detriment of overall wellbeing of their citizens.

Yet the changes apparently occur in an uneven way, multiplying the societal heterogeneities. Alongside poor regions dominated by agricultural activities, one finds regions with clusters of advanced low-tech as well as high-tech industrial activities capitalizing on cheap labor. Many of the fast-changing economies give home to companies that copy technologies as well as others that may be innovators at the technology frontier. The mere availability of advanced technologies does not imply that it is also diffused to society. At the same time, the economic weight of the largest transnational companies matches that of smaller countries, yet their political power

DOI: 10.14267/phd.2016013

often stays informal. What appear to be unsustainable political or economic arrangements continue to survive for decades. Socio-economic development is thus the outcome of the combination of technological, economic, demographic and political change. Change in these different domains need not be synchronized, causing accelerations, slowdowns and lock-ins.

Perceiving economic development as the co-evolution of different – but interlinked – economic (and social) domains (such as companies, industries, finance, public sector) is at the heart of neo-Schumpeterian economics (Nelson, 1994). Following a definition proposed by Hanusch and Pyka:

"*Neo-Schumpeterian economics deals with dynamic processes causing qualitative transformation of economies driven by the introduction of innovation in their various and multifaceted forms and the related co-evolutionary processes*.

This definition includes the three characteristic features of neo-Schumpeterian economics (…), namely (i) qualitative change, affecting all levels and domains of an economy, (ii) punctuated equilibria i.e. periods of radical change followed by periods of smooth and regular development, and (iii) pattern formation: despite the true uncertainty, the processes to be observed are not completely erratic but spontaneously structuring." (Hanusch and Pyka, 2007; p.1161, emphasis in original)

Scholars have long tried to make sense of these tectonic changes; and among the many factors that drive these trends, highlight the role of learning and innovation, alongside changes in capital and labor (Freeman, 1995; Lall, 1992, 2001). At the root of such transformations, one can find the innovative activities of companies that are incessantly seeking new ways to improve their position on the market and outsmart their competitors. They may introduce new or improved products that the world – or their customers have never seen, change the way of production or delivering their goods. In an analogy of introducing new products to the market, the concept of innovation as a source of deeper transformations refers to the introduction of institutional and organizational changes as well as their diffusion. A crucial observation to make is that the introduction of novelties and their diffusion occur over time, in a given socio-economic context, and necessarily interacts with its environment. This implies that interpreting innovations necessitates a specific context – which is a main reason why this dissertation has decided to focus on an economic (and technical) domain: the aerospace industry.

DOI: 10.14267/phd.2016013

The aerospace industry provides for an excellent object of study change in a co-evolutionary perspective, as it simultaneously influenced by and influencing economic, political and technological developments. It appears to be more globally spread than ever before: parts and components of the most modern Airbus and Boeing jets are produced (apart from Europe and North America) in China, India, South Korea or Mexico; advanced regional jets are designed and produced in Europe, Brazil, Russia, or Japan. At the level of producers, we observe Schumpeterian dyanamics in action: after European producers Fokker and British Aerospace exited, first Bombardier, then Embraer of Brazil even became world leaders. The military industry is also thriving, new generations of fighter jets are developed in the US, Russia and China (Deloitte, 2014; Medeiros, 2005). In short, the fast-evolving aircraft industry provides for an ideal terrain to study the co-evolutionary forces in technology, economics, politics and industrial organization. Many of its domains have been studied in great details by a variety of disciplines, by natural as well as social scientists. Our investigation is primarily, but not exclusively, of an economic nature, since we aim at understanding, describing and explaining the forces behind catch-up and eventual changes in industrial leadership in the aircraft industry. We address the problems of entry and catch-up of latecomer companies, changes in the global distribution of labor, in the interdependence of economies, expands and deepens technological capabilities, and its potential impact on global political power. The aircraft industry lies at the center of these processes in all its aspects: it is a capital- and knowledge-intensive, strategic sector, characterized by high value added and high incomes (Prencipe, 2013). Beyond all these, the aircraft industry is structurally connected with one of the largest service block in the global economy, which is serving hundreds of millions. This has also a major stimulating role for the development of the sector and its innovations.

A number of widely discussed aircraft development programs in South America and Asia testify for the innovation and industrial policy ambitions of many emerging economies. In the Peron years, Argentina became one of the few capable of making jet engines, and subsequently launched many military-oriented aircraft programs, including the IA 63 *Pampa* jet trainers. Most of the programs failed and Argentina's capabilities today consist of merely maintenance and overhaul (Hira and Oliveira, 2007). Brazil has gained fame for giving birth to Embraer, one of the only emerging multinational companies in the aerospace industry. Embraer's many aircraft designs, starting from the EMB-110 *Bandeirante* commuter prop to the currently produced E-Jet family of

DOI: 10.14267/phd.2016013

regional jets, have become globally successful export products (Cassiolato, 2001; Marques, 2004; Goldstein, 2002a,b). The former president of Indonesia, Habibie, was a leading figure in establishing the Indonesian aerospace industry, which co-produced and co-designed two turboprop commuters, the CN-212 *Aviocar* and the CN-235, with CASA of Spain. However, it struggled on the export markets and its more ambitious indigenous design for a regional jet became a major failure (McKendrick 1992; Eriksson 2003). Neighboring Singapore became a global player in the maintenance, repair and overhaul (MRO) industry, and a producer of advanced aircraft parts and subsystems, but it never aimed at developing an indigenous aircraft. South Korea and Taiwan, both heavy defense spenders, have both gained capabilities to produce aircraft parts and components, and strengthened their positions in the global supply chain (Texier, 2000). India's Hindustan Aeronautics (HAL) has developed and produced a number of jet fighters (such as the HF-24 *Marut* and the *Tejas*), trainers (HPT-32 *Deepak* and the *Kiran*) and helicopters (*Dhruv*) in the past fifty years. The Indian Space Research Organisation ISRO is among a handful of global launch service providers, and India is fast becoming a global player in the avionics market (Baskaran, 2005; Mani, 2013). In its aerospace companies scattered around the country, China has produced a large number of military fighters of many generations, trainers and transport aircraft, helicopters, as well as a number of civilian turboprops and jets, mostly for domestic use. The ARJ-21 regional jet marketed under the Comac brand and the C-919 large civilian aircraft currently in development are yet to receive foreign airworthiness certificates necessary for export, but have received global attention. Airbus and Embraer have recently established final assembly lines in China, while parts and components producers increasingly open new establishments in China. Space research has traditionally been advanced, and in 2003, China became the third country in the world with human spaceflight capability (Nolan and Zhang 2002; Goldstein 2006). In sum, many non-European or American countries have witnessed the rise and fall of aircraft industries, varying largely in their scale and lengths of production cycles and technological capabilities acquired. While only a selected few appear to have been catching up with the global leaders, many others keep trying to repeat their success, at very high costs. It is therefore crucial to understand the nature of a catch-up cycle.

Similar to countries, companies have risen and fallen in the past decades, in all segments of the aircraft industry. Most of the studies on the dynamics of the aircraft manufacturing industry have concentrated on companies that are top-tier producers of

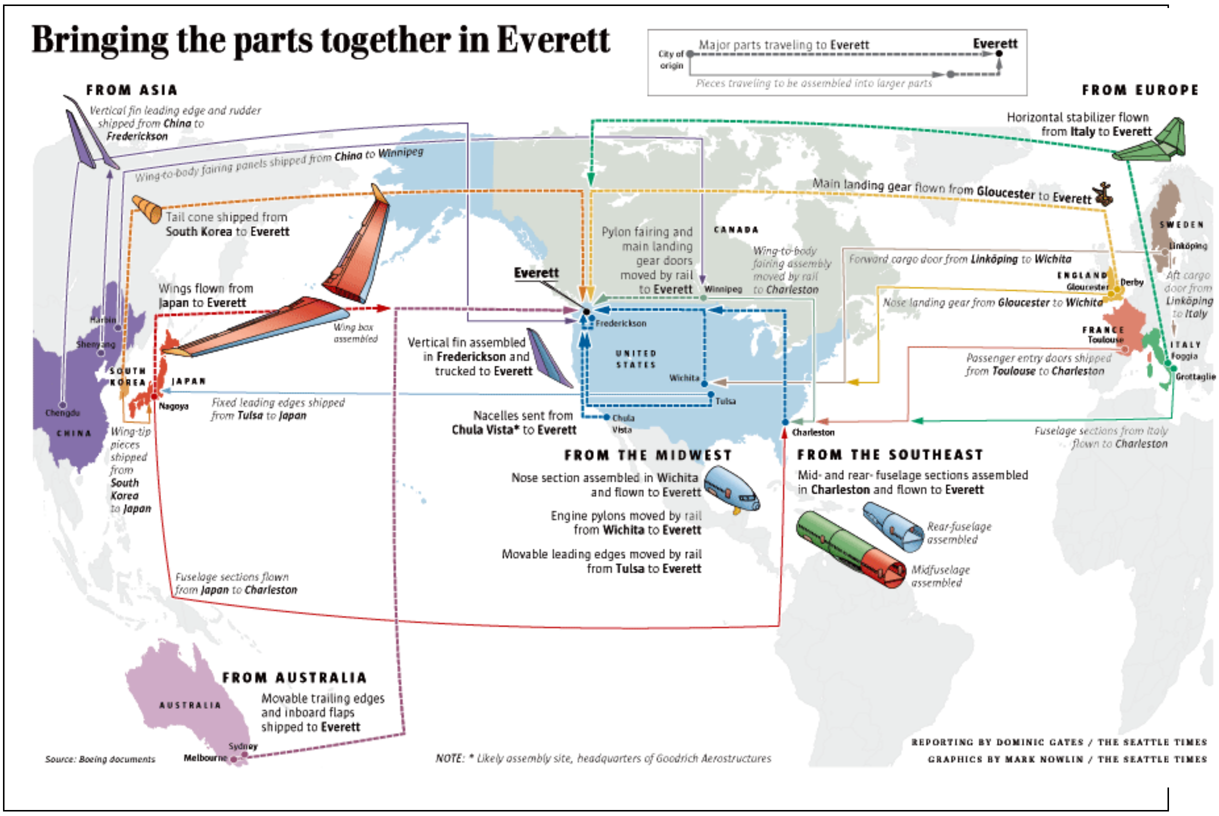
DOI: 10.14267/phd.2016013

large civil aircraft (Moran and Mowery, 1991; Golich, 1992; Frenken and Leydesdorff, 2000; Pavcik, 2004; Kechidi, 2013, Prencipe, 2013). The historical competition of makers of large civil aircraft has consolidated into the Boeing-Airbus duopoly by the turn of the millennium, but the regional jet market continues to witness turmoil, as it has for the last four decades. Many companies from around the world have or had stakes in this market which is intentionally eluded by Boeing and Airbus, including those with a long tradition of constructing aircraft such as Fokker, Canadair or British Aerospace and its predecessor Hawker Siddeley, newcomers such as the Brazilian Embraer or the Chinese Comac that aims to use this as a stepping stone for entering the large civil aircraft market. Many of these companies emerged as the largest producer for some years, but none of them managed to sustain their top positions for as long as a decade. Some, such as the Short Brothers, Fairchild-Dornier, or Indonesian Aerospace have launched regional jet development programs that never reached production phase, and the heavily indebted companies have effectively exited the market or were acquired. Understanding the future directions of global reorganization in this industry segment will certainly benefit from uncovering the driving forces behind past instances of catch-up and leadership change.

Recent trends of globalization and the expansion of transnational companies in the world economy has created new kind of opportunities for latecomers. As illustrated in Figure 1.1, the Boeing 787 *Dreamliner*, one of the most advanced aircraft produced today integrates parts and components produced in America, Asia, Australia and Europe. Suppliers to the *Dreamliner* had already demonstrated their capabilities in a thorough vetting procedure. Joining such programs for latecomers may be considered as a strategic step in their endeavor to upgrade activities. Late industrializers that connect to lower tiers in the global value chains possess required capabilities and devise adequate strategies may upgrade to higher value added activities. What these capabilities and strategies are, and what kind of state intervention may be necessary to support them, remains an area of heated debate (Gereffi et al, 2001; Humphrey, 2004; Schmitz, 2004; Szalavetz, 2013).

DOI: 10.14267/phd.2016013

Figure 1.1 The global supply chain in the case of the Boeing 787 "Dreamliner"



Source: "Boeing 787: Build globally, assemble locally" *The Seattle Times*, September 11, 2005

We expect to find the Neo-Schumpeterian school of thought to offers the most relevant framework to understand the co-evolutionary processes in aerospace. Given that it is a complex system, with multi-level multi-level interactions, it is unlikely that any single theory could explain and predict the changing competitive landscape, the sources of market power, and the changing locations of production. In these changes, time and technological capabilities (alongside physical and human capital) are elements that cannot be overlooked, which creates a major challenge for theories on market equilibrium in the neoclassical tradition. While political economy may offer partial explanation given its ability to incorporate political actors and values and interests in the conceptual framework, it focuses less but less on industrial dynamics and the role of technology & innovation. The theory of Complex product systems (or COPS, in short, see Dosi et al, 2003; Hobday et al, 2005) may be relevant for a cross-sectional analysis of the aircraft industry, but it provides little support to study evolution of industries over time (Davies, 1997). We argue that research should focus on the industry level – the "meso-level" which we considered to be in close interaction with micro- and macro

DOI: 10.14267/phd.2016013

developments in the business and political landscapes, be evolutionary and system-oriented in its approach. This will be further discussed in Chapter 3.

1.2 Research Design

The general question 'What has changed, at what pace in the global aircraft industry?' can be better operationalized if re-formulated it into three more specific research questions, zooming in from a macro to a micro perspective:

> Q1: How did the international division of labor (in terms of production, trade, innovation) change in the global aircraft industry in the past half a century? What are the main patterns of internationalization in the industry?
>
> Q2: Why have some countries succeeded while others failed to catch-up in aircraft manufacturing? What strategies did governments follow in emerging economies that fostered sustained growth in the sector?
>
> Q3: At the level of companies, in the regional jet segment, what have been the drivers of successive catch-up and leadership changes?

The three questions are connected by the overall aim of investigating the same phenomenon – change in the global aircraft industry – from multiple perspectives. They are distinguished by the different points of entry, their focus on three different aspects and levels of change. In order to establish the boundaries of the research, we introduce a few definitions for central concepts used in this dissertation. This involves addressing four main methodological issues identified at the outset of the study:

1. The level of analysis problem
2. The delimitation problem (time, space, activity)
3. Overcoming the problem of secrecy, confidentiality, and lack of information
4. Sample selection and generalizing results

The first problem concerns the selection of the most appropriate unit of analysis to address the research questions. The selection of the level of analysis, data and methodology are closely linked, and influence outcomes of the study. For instance, if we choose to focus on latecomer companies only, we may either overestimate the role of a company and may be unable to understand external sources in details. Choosing countries as the unit of analysis, our results may be biased by the fact that the largest companies have production and even R&D activities in multiple locations within and

DOI: 10.14267/phd.2016013

across countries, which implies that in different locations a company is affected by different factors. Our chosen solution to tackle these potential biases is to make use of the larger scope allowed by the scale such a dissertation and have multiple points of entry: study country-dynamics as well as company dynamics. Chapters 2 and 4 will therefore have a more macro focus, primarily on countries, while chapter 5 will be look more closely at the factors influencing company strategies as well as their impacts on industry dynamics.

The second problem is delimiting the scope of our research, in time and space. As for the time horizon, on the one hand, we recognized that studying evolution requires taking a sufficiently long perspective to include company entries and exits, different types of technological changes as well as multiple waves of business cycles. On the other hand, a too long time horizon makes it difficult to give a detailed account of economic, technological and institutional history. Aerospace as an industrial activity (as opposed to inventiveness), emerged about a century ago, and underwent a radical transformation following the 1950s with the diffusion of the jet engine in commercial aviation. We take this moment as the start for our rough delimitation when we aim to find answers to the first two research questions. As the third research question focuses on regional jets, the starting point for this investigation will be the early 1980s, with the emergence of this segment.

Delimitation of the study also involves making choices on industrial activities of interest. There are two main options: taking a company-based approach (everything a company that identifies itself within the aerospace sector does is of interest for the study), or a product-based approach (only industrial activities related to specific aerospace products are of interest). We expect that for a study on the history of the industry, the product-based approach provides more specific results, while a company-based approach is more suitable for an explorative study – thus opt for a product-based approach, wherever it is possible. This is also in line with the standard international statistical definition of the aerospace industry (that is, the manufacturing of aircraft, spacecraft, their parts and components, including engines and propulsion systems). However, remain attentive to the fact that this definition may not be easily applicable in an infant industry context, as nascent companies that produce aircraft parts may be active in other heavy or high-tech industries as well, or in the turbulent era of nascent technology, where new products emerge outside the existing classes. Difficulties may also arise when the unit of analysis is a complex product, such as a specific aircraft,

DOI: 10.14267/phd.2016013

with parts and components are produced around the world, by companies that may be competitors of one another in a different market.

One of the motivating factors for this research is the surprisingly little comparative global statistical data available on the industry, which may be linked to the difficulty in finding definitions. This is particularly surprising, given the considerable public interest in the aviation industry. The most easily available sources are international business statistics (such as UN / UNIDO, OECD, or Eurostat), and reports of consultancy companies (i.e., Deloitte, 2014). However, when carefully studied, it is clear that these sources are either not comprehensive and lack many of the emerging economies for many of the years, or – in the case of the latter reports – are less rigorous when aggregating incomparable figures. Without comparable production and export statistics, it is very easy to exaggerate any threat to established structures posed by new entrants to the industry, or overestimate the success of an industry that achieved the maiden flight of a new model but failed to sell to airlines.

Since aerospace producers are typically large firms, often without significant domestic competition, and often dual producers of commercial as well as defense products, access to data and confidentiality become serious limiting factors. The reasons for unavailability of data differ from country to country, but a few common patterns can be observed. Most of the industrialized economies (members of OECD) report business statistics since 1970, but for earlier years it is mostly published as part of the more aggregate transport equipment manufacturing branch. Former socialist countries (from Central Eastern Europe to China) have been secretive about information on the sector during the Cold War years given their association to national security. Even the otherwise highly insightful estimates in declassified CIA reports (Maddison 1998) do not offer data on this industry for the USSR. (Spy agencies appear to have only been interested in aerospace as a source of military capabilities and less as a source of wealth creation.) Even today, the Russian Federation does not publish sectoral value added or sales figures, thus impeding historical extrapolations. The high degree of concentration of industrial activity is another major difficulty, especially in newly industrializing economies. Often there is only a single enterprise. In order not to jeopardize the respondents' anonymity in industrial surveys, statistical offices are forced to publish branch level aggregate figures when the industry consists of only a handful of firms. In other cases the manufacturing activity in the sector was simply too small to be measured separately. But even if domestic aircraft manufacturing activities were measureable,

DOI: 10.14267/phd.2016013

they were short-lived (i.e. some Latin American countries) or could not be differentiated from maintenance, repair and overhaul activities. In sum, it is not surprising that no comparative study was ever published on the growth of aerospace manufacturing. Yet, in a sector with a low number of producers and highly visible products, at least the commercial data unavailable in national statistical publications can be obtained from company reports or secondary sources.

It is very important to distinguish the business activity of aircraft manufacturing from air transport services provision. The production of planes (aircraft parts, subsystems, etc.) is the first activity: aerospace products and parts manufacturing, while the airlines industry forms part of “air transport services”. This dissertation deals with the manufacturing industry only. “Aerospace” covers aircraft, spacecraft, their parts and components (including engines and propulsion systems), according to the definition of class 303 in the ISIC Rev. 4 definition. Within aerospace, it is extremely difficult to distinguish industrial activities based on their purpose, whether products are commercial or military oriented, due to the fact that all the large producers are active in both market segments and many of the products and components are of dual use. Commercial aircraft development directly benefits from defense-oriented R&D subsidies and military orders received by the same company. It is somewhat easier to distinguish aircraft and space vehicles manufacturing, although not all statistical agencies provide such disaggregated information and not for all years. For the United States, the 2010 *Annual Survey of Manufactures* provides an example (see Table 1.1): the first three sectors within Aerospace product and parts manufacturing are responsible for aircraft, engines, their parts and auxiliary equipment (336411 to 336413) that constitute 85% of the industry in terms of value added, and 82% in terms of employment. The rest of the industry is related to the manufacturing of guided missiles and space vehicle. Official Chinese statistics, for the few years where a distinction is available, provide a similar share of about 15% for the space industry, but this proportion is unknown for most other Western producer countries. In these cases it is fair to estimate that the share is lower given their more limited space activities. At the same time, trade statistics make the distinction between commercial and military as well as between air and space activities possible. Whenever we present export and import data, we focus on the commercial aircraft segment only.

DOI: 10.14267/phd.2016013

Table 1.1 The elements of Aerospace Manufacturing in the U.S. Annual Survey of Manufactures (2010)

NAICS 2007 Code and Description		Subsector's share in	
		Employment	**Value Added**
3364	**Aerospace product and parts manufacturing**	**100%**	**100%**
336411	Aircraft manufacturing	38%	49%
336412	Aircraft engine and engine parts manufacturing	17%	15%
336413	Other aircraft parts and auxiliary equipment manufacturing	27%	21%
336414	Guided missile and space vehicle manufacturing	12%	11%
336415	Guided missile and space vehicle propulsion unit and propulsion unit parts manufacturing	4%	3%
336419	Other guided missile and space vehicle parts and auxiliary equipment manufacturing	2%	1%

Source: United States Census Bureau

The existing literature has no single solution to overcome all these potential biases. Some authors have looked at the sector in countries (Hill and Pang; Goldstein, 2002; Marques, 2004; Mani 2013); others have taken a regional approach and studied aerospace clusters (Niosi and Zhegu, 2005 and 2010). In this dissertation, since we aim at understanding a complex problem that is the co-evolution of technological, economic and political factors in the long-term development of an aerospace industry, we decided to approach the object of study with multiple levels of analysis. Since co-evolution can occur in different layers, we need to allow a certain degree of flexibility. In different chapters, we take a different angle for the analysis. We study country-level dynamics in Chapter 2 to get a comprehensive view on the overall evolution of the industry across time. In Chapter 4 we focus on the aircraft industry in selected country contexts which allows an assessment of the innovation system and the evolution of its main components over time. Naturally, among the actors, we will also study the history of companies. Finally, in Chapter 5 the main unit of analysis will be companies, allowing identifying windows of opportunity and their interplay with company strategy, in order to understand Schumpeterian dynamics. We assume that such a multi-level analysis is inevitable to draw sound conclusions.

Earlier studies focused on selected (macro- and meso) (Mani, 2013; Marques, 2004; Niosi and Zhegu, 2005; Vertesy and Szirmai, 2010; Vertesy, 2011), the novelty in this dissertation is to encompass dynamisms observed at three different levels: at that of countries, industries and companies. This dissertation also combines quantitative and qualitative study of the evolution of the industry in the following way. As it is very

DOI: 10.14267/phd.2016013

important to put micro-level and qualitative developments in perspective, before any further investigation, Chapter 2 offers an overview of the contours of the industry in aircraft producing countries, providing a quantitative background. Here, we decided to be as universal as possible. This will also allow us to select country and company cases for a more in-depth study. For selecting the sample of country case studies in section 4, our aim was to have a broad geographical and temporal coverage, in order to be able to study the differences and similarities in the long-term evolution of the industry, and also keeping in mind the aim to sample from cases of success as well as of failure. Especially this latter seems to be systematically underreported in the literature, leading to repetitions of historical mistakes. It has been often argued that a quantitative study fits best the aim of comparing the scale across countries, growth over time, but case studies are more appropriate when the research is of descriptive, explanatory nature and the outcomes have to be evaluated considering the real world context (Yin, 2012). A potential bias in case study designs is the tendency of exaggerating results – this we try to balance with our comprehensive, multi-level design and backing up observations with comparative statistics. At the same time, we expect to observe unique, often incomparable events, for which we try to follow an inductive approach.

Thus we can summarize our approach in Table 1.2. In brief, we answer the first research question in Chapter 2 with the help of an empirical study of the industry's evolution based on of statistics compiled by the author on production, value added, trade and innovation, from official sources augmented when necessary in order to obtain comparable time series. Based on the empirical findings in Chapter 2 and on a review of the literature on latecomer industrialization, innovation and capability building in Chapter 3, we answer the two subsequent research questions using qualitative case studies, structured in conceptual frameworks presented in the respective chapters. Chapter 4 focuses on the evolution of sectoral innovation systems, and we conduct a historical-institutional study of country-catch-up using a framework of innovation system dynamics. Next, Chapter 5 discusses industrial leadership change in the regional jet segment in light of windows of opportunity and preconditions. In this piece of research, all cases of leadership change are studied in-depth, with a focus on companies as well as exogenous and endogenous events that may have triggered leadership change. In order to be comprehensive and objective, we study not only the companies that became the leaders, but also incumbents and other challengers. For both Chapters 4 and 5, we rely on data collected from triangulated sources that include archived company reports, trade journals and newspapers, secondary studies, as well as official statistics. A combination of these sources has proved to be very insightful for the aerospace industry with a highly concentrated company structure, and where other methods, such as surveys are less effective.

Finally, the conclusions from the studies at the various levels are brought together in Chapter 6, which revisits the research questions and summarizes the results.

Table 1.2 A schematic overview of the research design (research questions and applied methodology)

Research question, in brief form	Chapter	Unit of analysis (region of focus)	Methodology applied
1. The evolution of the global aircraft manufacturing industry and internationalization	Chapter 2	Country, world region (global)	Harmonizing data from different statistical sources; comparative analysis of descriptive time-series statistics
2. Understanding successful and failed strategies of catch-up	Chapter 4	Sectoral innovation systems (latecomer economies)	Comparative case studies using a framework of "innovation innovation system dynamics" (based on neo-Schumpeterian literature)
3. Industrial leadership changes in the regional jet segment	Chapter 5	Companies (from latecomer and advanced economies)	Case studies based on the conceptual framework of windows of opportunities–strategic response – preconditions

In sum, through this multi-level analysis, this dissertation aims to increase our understanding of the constant competitive struggle between incumbents and new entrants, and tries to understand long-term change by disentangling the various sources of incremental and radical system changes.

DOI: 10.14267/phd.2016013

DOI: 10.14267/phd.2016013

Chapter 2: The Two Waves of Internationalization in the Global Aircraft Industry

Note: A modified version of this chapter is being published as “The Contours of the Global Commercial Aircraft Manufacturing Industry.” In S. Eriksson, H-J. Steenhuis (eds.) *The Global Commercial Aviation Industry*. New York: Routledge.

2.1 Introduction

The capacity to design and produce an airplane is very much distributed around the world today. Planes flown by major airlines today (see also Figure 1.1) contain advanced parts and components produced in American, European and Asian countries. This is fundamentally different compared to how the industry was organized in the 1960s, when aircraft design and engineering, manufacturing and product support were typically vertically integrated activities, conducted in the same country, even in the same company. In all these activities the dominance of producers from the United States was overwhelming. Yet, today, news headlines in the US not only celebrate new technological achievements, but also fret about changing market conditions and perceived global shifts in the industry. Heated debates were triggeder by developments such as when Comac, the new Chinese aircraft manufacturer announced the setting up of risk-sharing partnerships for the development of the C-919 – a mid-range jet that would make it a direct competitor of Boeing and Airbus –, the opening of final assembly lines in China by Embraer and Airbus, or Bombardier establishing a component manufacturing centre in Mexico.[1] Some analysts, such as MacPherson and Pritchard (2003) link the increased use of global suppliers to a significant reduction in the number of aerospace jobs in the US and fear about its effect on future competitiveness of incumbent US producers. Others see this high-tech industry as an instrument for moving up the value chain and a way of breaking out of middle-income trap (Wade 2010). Commercial aircraft manufacturing is an important economic activity which can generate significant export revenues and demand for highly-skilled

[1] See i.e. Crooks, Ed “GE to sign slew of China deals in jobs boost” *Financial Times* 18 Jan 2011; Reed, John “Aerospace: Manufacturing takes off” *Financial Times* 16 April 2012

DOI: 10.14267/phd.2016013

employment – beyond its perceived contribution to national security. For the sake of a sober discussion on the real impact of internationalization in the aircraft industry, and in order not to overestimate its scale, in this chapter we set out to analyze the evolution of the industry in aircraft producing countries, as reflected by statistical evidence.

More specifically, this chapter investigates the changing geographical distribution of aircraft production, trade and innovation activities, and the major underlying dynamics. As discussed earlier, we focus on aircraft manufacturing at the country level, as defined in international statistics, and where possible, distinguish commercial from military-oriented activities.

2.2 The state of commercial aircraft manufacturing and its main development trends

2.2.1 How to measure country performance?

The most commonly used indicator to measure the size and changing geography of the global commercial aircraft industry has been the relatively most easily available export statistics and company sales data. The main advantage of export statistics is their global coverage and the systematic collection and publication of data from both trading partners. At the same time, export data does not distinguish trade in new or used products, so it is only a second-best indicator of successful foreign sales of domestically produced aircraft, if figures are biased by the foreign sales of used wide-body aircraft in the million-dollar price range. This makes it particularly difficult to compute indicators of international specialization and comparative advantage of countries. Company sales data offer better insight into the performance of actual products, however, not all aerospace companies are publicly traded or are forced to publish their detailed results. More aggregate national statistics for the aircraft industry on sales and value added are therefore better indicators of actual aircraft production activities, however, as will be discussed below, such figures may be too aggregate and make it difficult to distinguish commercial from military production.

Given these considerations, this chapter primarily relies on a combination of data on exports, production (value added) to draw the contours of the commercial aircraft industry and the latest developments in its internationalization.

DOI: 10.14267/phd.2016013

2.2.2 About the sources

The statistics described here offer a historical overview of the growth of the aerospace industry since the 1970s in 45 countries. The core dataset originates from national statistical data, obtained directly from national accounts data in yearbooks, data from manufacturing surveys, but also from UNIDO, OECD, Eurostat and other international statistical databases, or compiled datasets of the Groningen Growth and Development Center (GGDC). In some cases, data were augmented by data from company reports. These datasets have been scrutinized and adjusted for purposes of cross-country comparisons; values in national currencies were converted with industry-of-origin unit value ratios in all possible cases. Detailed information on data sources and extrapolation methods used for each country are provided in Vertesy (2011).

The aim was to provide as reliable data as possible for the overall time span, and provide as many countries as possible for the last 25 years on value added, gross output (sales), employment and exports. Unfortunately investment figures (such as gross capital formation, R&D investment) were unavailable on a yearly basis and providing incidental figures are meaningless in this context where project success depends on investment accumulated over decades. Yet it remains our hope that transparency in the sector will increase (at least in the archives) so that future research will be able to fill this gap.

Before turning to a discussion of the changing patterns of production and trade in aircraft, we first look at how demand for aircraft has changed over the past decades. Air transport growth is the key commercial driver of new aircraft sales, a major “pull factor” for growth of aircraft manufacturing.

2.2.3 The changing landscape of demand for new aircraft

World air traffic has been growing rapidly over the last four decades. The number of air passengers has grown more than eight-fold between 1970 and 2010. To better understand the volume growth at the global scale, let us suppose that every air passenger flies only once a year. While only every twelfth person could have flown in 1970, about every third citizen of the world could have experienced this fastest means of travel in 2010. In reality of course, access to air travel depends on income, and until

DOI: 10.14267/phd.2016013

as recently as the year 2000, some 90% of the world's air passengers came from high- or upper middle income countries. Yet as new economic powerhouses emerge in East Asia, so does the geographical distribution of demand for air transport services change. According to World Development Indicators of the World Bank, three-quarters of air traffic concentrated to Western Europe and North America in 1970, and this share has gone down to half by 2010. Over the same period, Latin America and the Caribbean region maintained a flat 7% while the East Asia and Pacific region doubled its share to nearly a third by 2010. This latter region has, for the first time, overtaken the European Union in terms of number of passengers carried.

For a long time, the aviation market was very limited in many of the emerging economies, despite their large territories. China was one of the best examples of an "earthbound" country. Even in 1980 it showed passenger-kilometre levels similar to that of European countries before the jet age. The number of air passengers in China in 1990 was similar to that of South Korea. The passenger levels of 2006 are still lower than the US levels of 1970. Nevertheless, the growth of air traffic within and out of the country exceeded that of many countries with the largest air transport markets. Annual average growth in China between 1990 and 2007 was nearly 15.8%, while it was only 6.7% in the UK and 3.1% in the USA. It was only China that managed to sustain high growth rates – due in part to the very low initial levels of air transport. Still, there is a large potential for further growth, by further opening up the airspace for commercial traffic, improving air traffic control infrastructure and overcoming pilot shortage.

The growth of global air transportation has clearly gained speed after 1980. A major reason for this was a 1978 deregulation in USA resulting in the entry of new airlines and the expansion of services. Similar deregulation took place in Europe in the 1990s, but many of the emerging air transport markets remain highly regulated even today. To a large extent, the growth is constrained by infrastructural limitations and airport and air traffic management capacities. Nevertheless, many of the Asian emerging economies have made large investments into tackling these issues and have nurtured the largest airport development projects in recent decades.

Another way to measure the volume of air traffic is by looking at the sheer number of commercial departures. In emerging economies air traffic has been expanding at a much faster rate than in industrialized economies. The average rate for the period 1973-1990 was 4.5% for emerging and only 2% for industrialized economies. For the period 1990-2007 it was 5.8% and 3.8%, respectively. The most rapid growth in traffic in this last

DOI: 10.14267/phd.2016013

period was observable in China and Korea. Changes in air traffic are closely linked to changes in economic growth, and the above average GDP growth in Asia explains the above-average growth in traffic. Put in historical perspective, the number of airline departures in China in 2007 (1.75 million) was still lower than that in Western Europe (1.85 million) in 1973, not to mention the USA (7.93 million).[2]

Table 2.1 Demand Forecast for New Aircraft by Major Manufacturers

Company	**Boeing**		**Embraer**		**Airbus**		**Bombardier**	
Outlook Period	**2009-2029**		**2010-2029**		**2009-2028**		**2010-2029**	
A. Regional Aircraft								
Seating capacity definition:	<90 seats		30-120 seats		<100 seats		20-99 seats	
Market value (USD bln)	60		200		n.a.		~239	
Regional Market Size	Tot	(Share)	Tot	(Share)				
(new deliveries next 20 years)	1920	100%	6875	100%	8321	100%	6,100	100%
North America	800	42%	2400	35%	2899	35%	2,860	47%
Latin America	20	1%	575	8%	661	8%	350	6%
Europe	310	16%	1510	22%	2160	26%	(incl. CIS) 950	16%
Asia-Pacific	470	24%	575	22%	1374	17%	1580	26%
Of which P.R. China	*280*	*15%*	*950*	*14%*	*n.a.*	*n.a.*	*860*	*14%*
Russia/CIS	200	10%	405	6%	467	6%	n.a.	0%
Middle East	70	4%	240	3%	154	2%	(incl. Afr.) 360	6%
Africa	50	3%	220	3%	506	6%	n.a.	
B. Total Commercial Aircraft Market								
Total Market value (USD bln)	3,590		n.a.		3,100		n.a.	
All new deliveries next 20 years	30,900	100%			30,175	100%		
North America	7,200	23%			7,675	25%		
Latin America	2,180	7%			2,090	7%		
Europe	7,190	23%			7,585	25%		
Asia-Pacific	10,320	33%			8,726	29%		
Of which China	*4,330*	*14%*			*3,272*	*11%*		
Russia/CIS	960	3%			1,332	4%		
Middle East	2,340	8%			1,497	5%		
Africa	710	2%			1,270	4%		

Source: Boeing Current Market Outlook 2009-2029; Embraer Market Outlook 2010-2029; Airbus Global Market Forecast 2009-2028; Bombardier Commercial Aircraft Market Forecast 2010-2029

The efforts to bring aircraft manufacturing to Asia are reasonable in light of the economic growth predictions (Maddison 2007) and (related to these predictions) new aircraft delivery forecast of the world's four largest manufacturers (see Table 2.1). The

[2] Based on data from the World Bank World Development Indicators.

DOI: 10.14267/phd.2016013

Asia-Pacific region is expected to take up about a third of all new aircraft deliveries, becoming the largest buyer. Calculating in 2009 dollars, aircraft sales to Asia will be in the range of a trillion US dollars over the next two decades. According to all major manufacturers, China alone is expected to receive 11-14 per cent of all aircraft deliveries in the same period. North America and Europe remain neck and neck in the total forecast of both large commercial aircraft manufacturers accounting for about a quarter of global demand. North America will remain the largest market for regional aircraft (including both jets and turboprops), but predictions on the shares differ significantly (between 35-47 per cent). According to three of the producers, around one in every four new regional aircraft will land in Asia, only Airbus predicts a somewhat lower share.

If the various predictions are correct, every percentage point of market share translates into 3.1-3.6 billion dollars-worth of aircraft acquisition over the upcoming two decades. Such a growth is a clear indication of increased demand for aircraft and parts in countries of this group, considering also the additional demand for maintenance, repair and overhaul services. All these present strong incentives for a further globalization of aircraft manufacturing capabilities, and offer strong leverage potential for countries such as China to strategically define the terms of attracting foreign producers to manufacture at least some parts and components locally.

2.2.4 Business cycles in the aircraft manufacturing industry

Let us now look at aircraft manufacturing from the suppliers' perspective. The evolution of the global aerospace industry closely reflects major macroeconomic, technological and political events. The rapid expansion of air transportation was made possible by the diffusion of technological innovations such as the jet engine after World War II and the emergence of a dominant design of airliners, and was fueled by growth of the global economy. Continuous technological improvements in the civilian aircraft industry benefitted from military research and development activities in the aircraft and spacecraft segments, particularly in the context of the Cold War.

Accepting the limitation of official statistics discussed above, that for most countries it is not possible to disentangle air and space, and civilian from military production, it is still very informative to chart the trends of the aerospace industry. Even if the scale may differ, the cyclical trends are very similar for the largest segment, commercial aircraft. Table 2.2 provides an overview of the evolution of the global aerospace industry between 1960 and 2010. Over these five decades value added increased by a factor 3.5 to 136.6 billion USD, gross output increased four-fold to over 300 billion USD. The growth of the industry was not linear. Figure 1 shows a cyclical growth pattern with peaks in 1973-74, 1980-81 and 1991, followed by periods of decline. The most rapid growth in value added took place from 1995 to 2007 (annual average of 6.8%), the largest of the drops occurred in the years following the end of the Cold War (in average 7.7% annually between 1990 and 1995). Currently aerospace globally accounts for over 1.4 million jobs, which is already lower by 23% than at its peak in 1990. Between 1990 and 2007 more than 400 thousand aerospace jobs were lost around the world.

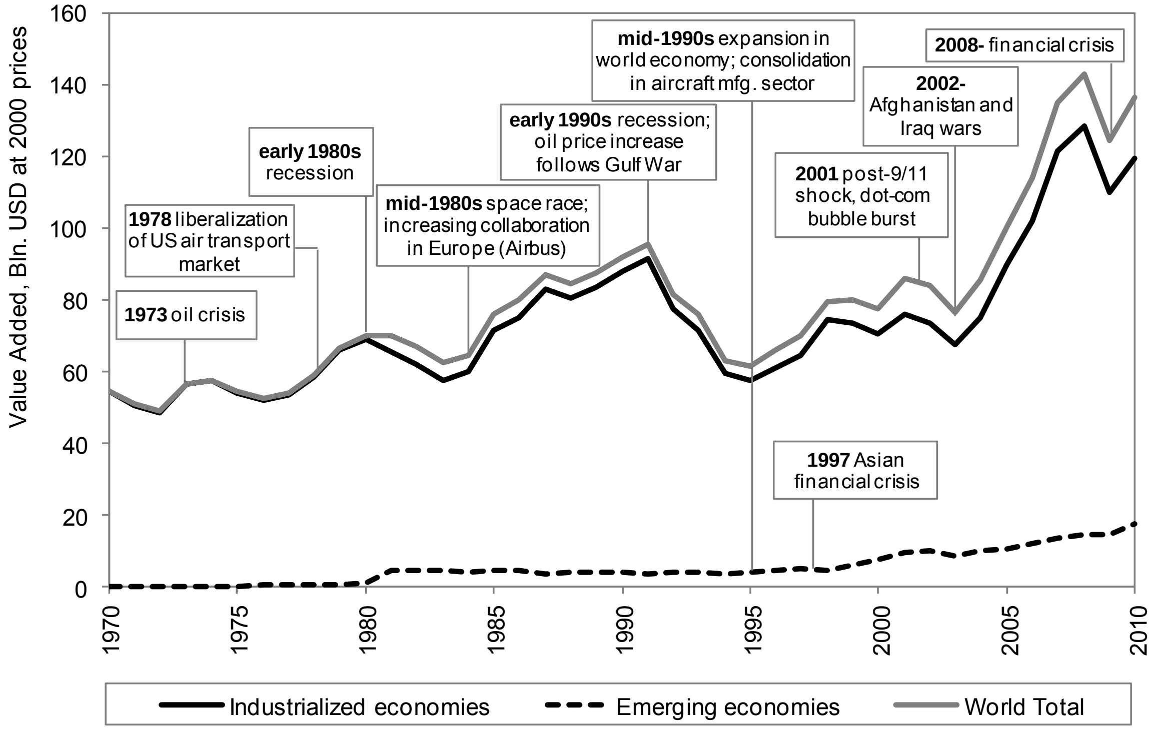
Table 2.2 Key indicators on the evolution of the aerospace industry, 1960-2010

	1960	1973	1985	1990	1995	2000	2005	2010
Total Value of Output (GO)	78,350	108,516	164,700	213,034	159,924	221,769	257,029	300,110
Gross Value Added (VA)	38,586	56,568	75,846	91,878	61,593	77,716	100,359	136,612
Total Employees (thousands)	953	1,075	1,680	1,839	1,669	1,531	1,357	1,324
Nr of Countries in GO sample	15	20	27	33	38	40	40	39
missing data for significant producers[a]	*6*	*6*	*7*	*5*	*1*	*0*	*0*	*0*
Nr of Countries in VA sample	16	23	31	34	40	42	43	43
missing data for significant producers[a]	*3*	*4*	*4*	*3*	*0*	*0*	*0*	*0*

Source: Vertesy (2011)
Notes: Data covers all aerospace producer countries, with the exception of the Russian Federation. (a) Countries in the sample with missing data most likely exceeding 100 million USD and value added exceeding 50 million USD.

DOI: 10.14267/phd.2016013

Figure 2.1 Evolution of the Aerospace Industry, 1970-2010



Source: Vertesy (2011, 2015)
Note: Includes, commercial, military and space segments

This production landscape is shaped by periods of economic expansion and recession in the major producers, such as the expansion periods of the late 1970s, the second half of the 1980s or the late 1990s, or the recessions following the oil crisis (1973-75), during the early 1980s the early 1990s and after 2008. Our consistent time series on aerospace producers ends in 2010, which prevents us from observing whether a full recovery from this latest crisis has happened yet. Recently published US and European data for 2012 shows that aerospace manufacturing, in terms of value added in real terms, has just recovered to pre-crisis levels.

During the four decades of the Cold War, the industry benefited greatly from high defense expenditures and from the fact that national security considerations often overrode economic considerations. However, it is noteworthy that the growth resulting from the increasing commercial sales during the post-Cold War era was more rapid than ever before. Global production in terms of value added increased 2.2-fold over merely 12 years between 1995 and 2007. To put this expansion in perspective, it took 30 years to achieve a 2.4-fold increase between 1960 and 1990.

DOI: 10.14267/phd.2016013

The aggregate figures presented here provide a comprehensive overview of the industry in the most advanced as well as emerging economies. Nevertheless, there are a few countries that are not included in the sample which have an impact on the total figures. As already mentioned above, the Russian Federation (and the former Soviet Union) has not published comparable output value figures for the industry. We estimate that Russian output may have matched US levels during the Cold War in military production, but commercial production was significantly lower given the more limited air transport industry in former communist countries. It is impossible to estimate how the inclusion of the Russia and the Soviet Union would influence global aggregate figures.[3]

Table 2.2 also indicates a growing sample size, which reveals the diffusion of the industry rather than missing data. Although times series data was incomplete for a few producers, this has only limited impact on the global aggregate. Countries missing from the early sample are China, the former socialist countries of Central Eastern Europe and Israel. China is the main source of inconsistencies over time, because our time series data begins with 1981.[4] However, it has a more limited effect on the global aggregates. In 1981 China was responsible for 4.7% of global production, in 1985 3.9%. The exact volume of production is unknown because most of the aircraft produced in China never left the borders of the country. Secondary sources suggest that military aircraft production (by far the largest share of total output) started to increase in the mid-1960s and peaked around 1980. We estimate that the inclusion of China would only increase the 1960 levels by 1-2% and the 1973 values by 2-4%. Other countries excluded from the earlier periods of the value added series include Israel (with no data before 1990) and Central Eastern European producers (Czechoslovakia, Poland, Romania, with no data before 1995) responsible for a significant amount of fighter and trainer production. At this point we cannot estimate their significance, but it is reasonable to believe that their aggregate would be lower than that of China in 1973 but higher in 1960. In sum,

[3] The rough military aircraft export trend indicator values published by SIPRI show the highest export activity between 1972 and 1989, with a peak in 1980. This corresponds to the production pattern observable in the most successful commercial planes (the Tu-134 and -154). The drop by the 1990s in both military and commercial production may have been as much as two-third the previous rates. If we added these trends to the global aggregate figures, the 1970s and 80s levels would be higher at least by 50% and the slump between 1990 and 1995 would look even more dramatic. The impact would be far less significant from the 1990s onward.

[4] Official series begin only with 1995. For details on Chinese extrapolation see Annex.

DOI: 10.14267/phd.2016013

the margin of error for the value output estimates could be between 5-8% for the years before 1981.

Similarly to value added, it is also very difficult to quantify the number of persons employed in commercial aircraft manufacturing. Even if one the entire aerospace industry is considered, the aggregate figures not only hide the civilian/military distinction, but also the qualitative change in labor in the industry. Some signs can be read from the trends. Cycles are similarly observable as in the value added series, and employment very does not deviate from these latter figures until the mid-1990s. Since then, however, value added increased while employment decreased. In fact, aerospace manufacturing (once again, assuming the broad statistical definition) employment peaked in 1990, at around 1.8 million persons employed, and over 500,000 jobs were destroyed worldwide until 2010. This is the outcome of a combination of factors, including the declining military expenditure after the Cold War, the consolidation of the industry through mergers and acquisitions or outsourcing activities, and the diffusion of information and communication technologies in all areas of design, production, maintenance, or management. For instance, advances in computational fluid dynamics and computer aided design virtually replaced wind tunnel tests and the need for model construction, this the three recent decades also represent the most significant qualitative change in aerospace employment. It is also interesting to look at the geographical breakdown of the reduction in jobs: aerospace employment in the US decreased by 400 jobs, and about a hundred thousand in both Europe, as well as in China. Surprising this latter may sound, in fact aerospace conglomerates were consolidated by reducing secondary non-aerospace activity of these firms (which were previously also included in the statistics). This global reorganization will be revisited in the section on internationalization; we conclude here that the overall industry (including the commercial segment) experienced significant efficiency gains but lost experienced human resources.

2.2.5 The largest industrial players

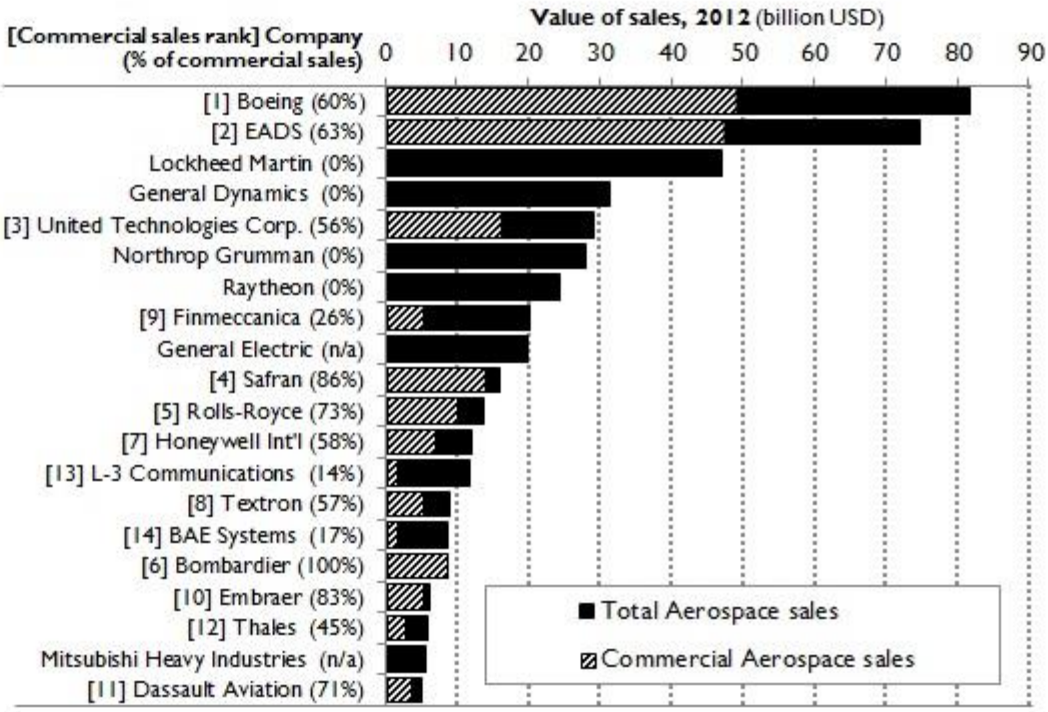
High market concentration characterizes the aircraft industry not only globally, but also within countries. The largest American and European aerospace and defense companies match and even exceed the size of entire countries' aerospace industries, both in terms of turnover as well as in terms of labor force. Boeing or EADS, with all their activities in the aeronautics (commercial and military) and space segments around the world

DOI: 10.14267/phd.2016013

combined, generate more annual sales and employ more persons than important aerospace producer countries such France, Germany or the UK. This degree of concentration is the result of a consolidation process of several decades ending in the late 1990s, through which the global industry underwent dramatic mergers and acquisitions and the formation of vast transnational corporations that integrate a large variety of aerospace and defence production activities and services.

Company size is important in the sector because only the largest players can raise sufficient capital (often in joint ventures) to finance the development of new projects with new technology.

Figure 2.2 Total and commercial segment sales value for the global Top 20 aerospace producers, 2012



Source: "Aerospace and Defence Top 100 Special Report" in *Flight International*, 24-30 Sep 2013, and the 2012 Annual Reports of the respective companies.
Note: Total sales value of companies excludes non-aerospace market segments companies, but includes sales at the defense market by the company together with all its subsidies around the world. Commercial includes all civilian sales, including the executive market. A commercial/defense breakdown was not available ("n/a") in the financial statements of a few companies.

Among the largest aerospace producing companies (Figure 2.2) one finds not only those whose main activity is to design, manufacture or sell aircraft such as Boeing, EADS, Lockheed Martin, Bombardier or Embraer, but also engine producers United Technologies Corporation, General Electric, Safran or Rolls-Royce, or avionics and

DOI: 10.14267/phd.2016013

other component and system suppliers, such as Honeywell or Thales. Many firms have heterogeneous activities, acting both system integrators as well as parts designers; some are active in both the fixed wing and the rotary wing markets. Much of the sales of the top 20 companies are military oriented, a few of the top companies (Lockheed Martin, General Dynamics or Northrop Grumman) are not active at all in the civilian aircraft market. For the other companies, the share of commercial sales (at least for those that report it) varies hugely, from about a quarter or less (BAe Systems or Finmeccanica) to around two-thirds (Boeing, EADS, Dassault), to a 100% (as in the case of Bombardier Aerospace). In fact, the top 10 companies change significantly if producers are ranked based on their commercial sales (this alternative rank is shown by the number in squared brackets preceding company names in Figure 2.2). In terms of geographical distribution, most of the companies have their headquarters in the USA (Boeing, Lockheed Martin, General Dynamics, Northrop Grumman, United Technologies, Raytheon, General Electric, to mention a few) or in Europe (e.g. EADS, BAe Systems, Finmeccanica, Thales, Safran), however, a growing share of their activities are more globally spread. At the same time, it is very telling for the type of internationalization of the global aerospace industry that Embraer, the fourth largest commercial aircraft producer, represents the only company in the list with its headquarters located in an emerging economy. In a more extended list of the global top 100 aerospace companies, there are already a few more companies originating from outside Europe or North America, including AVIC of China, Hindustan Aerospace (HAL) of India, ST Aero of Singapore and Korean Aerospace Industries (KAI).[5] These companies are parts and components suppliers as well as producers of defence products for local air forces, with the exception of ST Aero. This company, part of the ST Engineering group, has gained competitive advantage in the maintenance, repair and overhaul (MRO) and upgrade segments, offering a further example of the heterogeneity of what the broad definition of aerospace manufacturing entails. It is also the most internationalized among these latter.

[5] For a 2012 edition, see "Aerospace and Defence Top 100 Special Report" in *Flight International*, 24-30 Sep 2013. Hindustan Aeronautics was the 33rd largest aerospace company with 3.1 bln USD revenue; AVIC – publishing its audited financial results for the first time in 2012 – was the 37th with 2.7 billion USD revenue, driven by helicopter sales; ST Aero was the 53rd with 1.5 bln USD revenue and KAI the 55th with 1.4 bln USD. We also note that Fortune Global 500 ranks AVIC well ahead of many companies, although revenues stated are overestimated compared to the officially released Annual Reports.

DOI: 10.14267/phd.2016013

2.2.6 How significant is the aircraft industry with respect to the national economy?

In the leading industrialized economies that produce commercial aircraft, the size of the industry directly accounts for around 0.2 – 0.4% of GDP. Even larger shares can be observed in Singapore (over 1.5%), the United States (around 0.8%). The indirect impact of the aircraft industry is estimated to be as much as three times its direct size, considering its linkages with other sectors of the economy. The US shows a declining share of the industry with respect to its GDP following 1990, which is due to the declining defense and space activities after the end of the Cold War. An opposite trend is observable for most other producer countries, including Europe, Canada and China, where the relative size of the industry has been increasing since the 1990s.

The aircraft industry is one of the most important positive contributors to the trade balance of countries including the United States, France, the United Kingdom, Israel, Ukraine, Canada, Italy and Spain. With the shift of many industrial activities to cheaper locations, advanced economies have experienced increased global competition even in high-tech industries. As we have seen, aerospace has so far remained one of the last industrial resources of "the West", which is also apparent in their export figures. These leading producer countries show a revealed comparative advantage in aircraft trade[6], while only two emerging countries join them: Brazil in aircraft and Singapore in the export of parts and components.

2.2.7 General patterns of internationalization

It is a striking feature of the globalized world economy that the commercial aircraft industry, which was an important driver of the globalization process, has continued to be concentrated to the North Atlantic region in the past fifty years. The majority of the planes flown today around the world are sold Boeing or Airbus, and the majority of their parts have been produced in the United States or in Europe. While the emergence of low-, medium- and high-tech production capabilities have boosted the overall export performance of newly industrializing countries of Asia and of the Southern hemisphere so much that their share in total world merchandise exports has increased from 10% in 1970 to a third in 2010, the global share of these countries in aircraft exports still hardly

[6] This is based on the Balassa formula that measures the relative advantage of set of goods within a country's total merchandise exports.

DOI: 10.14267/phd.2016013

exceeds 10% today.[7] These figures are especially striking if contrasted with another transport manufacturing sector which is both capital and technology intensive, such as the automobile industry, which is much more evenly spread around the world, with every second car or truck being produced in Asia, more than a fifth in China alone.[8]

The world's growing appetite for aircraft is well reflected in the evolution of **imports**.[9] In the 1960s, the average volume of aircraft imports was around 8 billion US dollars (at 2005 prices), this increased to 18 billion in the 1970s, doubled over the 1980s as well as the 1990s surpassing 100 billion by 1999, topping at nearly 160 billion in 2013. Countries of Europe have always been the largest importers throughout these years, accounting for 53% of it in the 1960s, 35% in the 1990s as the consequence both of the short recession and of the large civil aircraft production picking up speed. In the subsequent years, imports increased once again, due to the intensive internal collaboration, reaching 65% of global imports in the 2010-12 period. Even if internal trade is excluded, the EU accounts for over 30% of global aircraft imports today. North America, a primary producer is less of an important importer, responsible for less than a quarter of world aircraft imports both in the 1960s as well as during the 2000s (23%), with a brief decline in the 1990s.

The region that experienced the biggest growth in aircraft imports was East Asia/Pacific. If we exclude here the OECD countries, we see that the region which on average accounted for merely 1.5% of global imports in the 1960s (hardly over 100 million USD, less than Latin America, began a strong growth period in the 1980s. Just as the economy of the region's countries started to grow fast, the region's global share in aircraft imports increased to 9.5% in 1990s, and further to 24% by 2010-12 – or, with OECD countries included (and the EU considered as a block), to 31%. An 8-fold increase between 1986 and 1996 brought the region to the center of attention. After the 1997 financial crisis which had an impact until 2000, the region's import growth

[7] For the sake of consistency, "newly industrializing countries" refer to a group of 20 Asian (exc. Japan and Russia), Latin American and African countries that have at some point in the past five decades produced aircraft or aircraft parts.

[8] Data source: 2011 Production Statistics of the International Organization of Motor Vehicle Manufacturers, [URL: http://oica.net/category/production-statistics/2011-statistics/; retrieved: May 2013]. Note that the share of emerging economies would probably be smaller based on turnover or value added, but these figures, and a real industry-of-origin exchange rate are not available to allow for a proper global comparison.

[9] Data presented below refers to aircraft imports obtained from UN Comtrade data, and were adjusted for inflation.

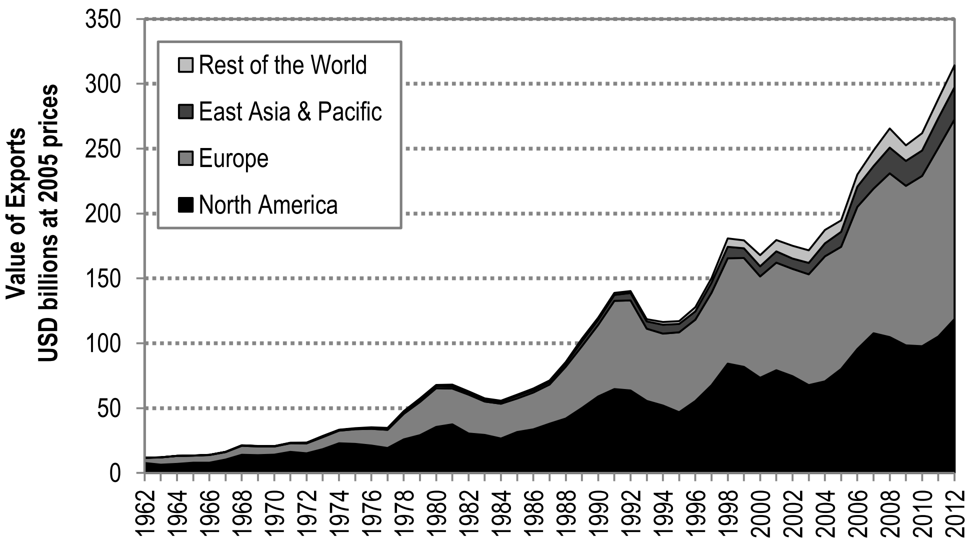
regained momentum, reaching 35 billion USD dollars in 2012, surpassing even that of the EU (not counting intra-EU trade).

Latin America, which was responsible for 7% of global aircraft imports in the 1960s, experienced a growth period in the 1970s, with import volume doubling but remaining flat around 1 bln USD in the following two decades. After the relatively weak decade of the 1990s when the region accounted for less than 2% of global imports, the 2000s saw a rapid growth to 7.4 billion in 2011, and the region's share reached around 5% in the 2000s.

2.2.7.1 Exporters and producers

The global evolution of commercial aircraft **exports** is punctuated by similar growth spurts and down-cycles that were observed in the case of production. As portrayed in Figure 2.3, North American and European exporters have benefited most significantly from growing demand abroad. Considering only the period between 1980 and 2012, their combined exports have more than quadrupled in real terms. Aircraft export figures have an important drawback, because they can include the sales of second-hand planes, which can be substantial considering that their prices can range between a few million to over a hundred million US dollars. Nevertheless, looking at the fifty-year trend shows interesting patterns on the slow regional redistribution of exports.

Figure 2.3 Evolution of commercial aircraft exports by selected world regions



Source: UN Comtrade; WDI
Notes: Aircraft exports defined by ISIC Rev.3 codes 792 (excl. 7925), 7131, 714 and 87411; Regions refer to the World Bank administrative regions.

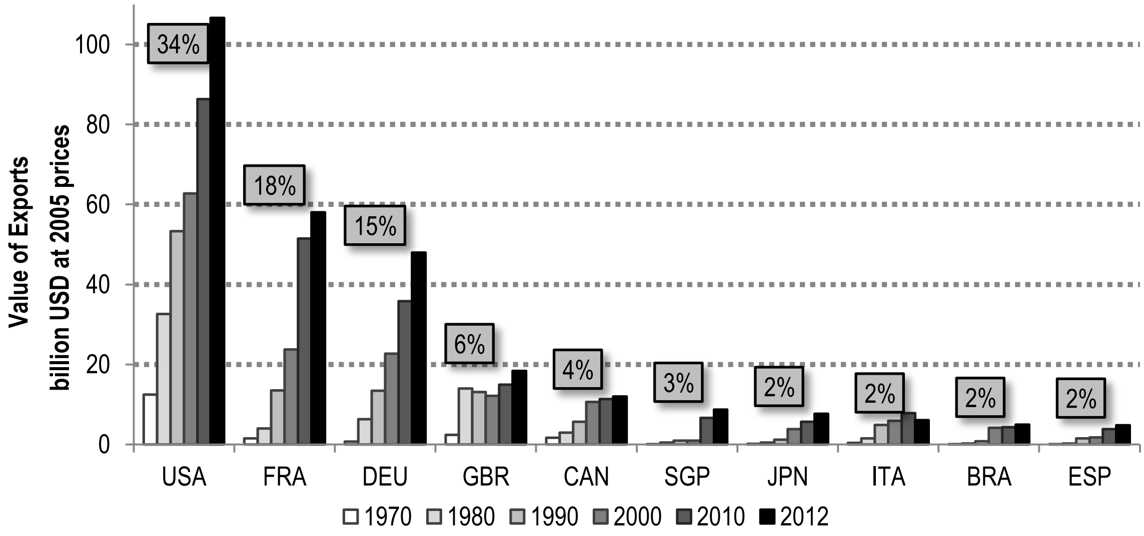
DOI: 10.14267/phd.2016013

One notable trend is the gradual loss of market share by North American producers. In the 1960s and 70s, 61% of commercial aircraft exports (of capitalist countries) came from North America, with more than half of it from the United States alone. By 2012, only 38% was originating from North America and a third from the US. Most of this lost market share was taken by Europe, which increased its global share in the 1980s and 1990s in particular, from 38% in the 1960s to 48% by the 1990s – and levelled off since (it was observed at 49% in 2012). Much of the gain is due to the increased collaboration between European countries, in the framework of the Airbus project. In fact, if we considered extra-EU exports only, Europe and the US are neck and neck accounting for around 40% of global commercial aircraft exports. As Figure 2.4 shows, the top five exporter countries that account for 77% of world exports, the US, France, Germany, the UK and Canada, have remained among the top five since 1980.

Considering the global growth trends since 1990, we see that the aircraft export of industrialized economies (mostly OECD countries) on total increased on average by around 3% a year, while that of emerging economies – due to their relatively smaller initial scale – grew by 12.5%. This owes much to the success of Brazil as an aircraft exporter, and Asian countries as parts and components exporter. Looking at emerging economies, we see that commercial aircraft exports experienced an eastward global shift, but not a southward shift: Latin America, despite the success of Embraer in Brazil and the growth of Mexican aerospace clusters, has a marginal export share. From half a percent in the 1970s, the region increased its global commercial aircraft exports share to 2.6% by 2012. In contrast, commercial aircraft exports from the East Asia and Pacific region have grown about twice as fast as the world average over the period of 1962-2012 (around 13% annual average growth in real terms), reaching a global share of about 8%. The three main engines of the region's growth have been Japan since the mid-1980s, Singapore since the late 1990s and, most recently, China. Other East Asian aerospace producers, such as South Korea or Indonesia, have achieved more moderate export growth since the 1990s.

DOI: 10.14267/phd.2016013

Figure 2.4 The 10 largest aircraft exporters (1970-2012) and their market share (in 2012, %)

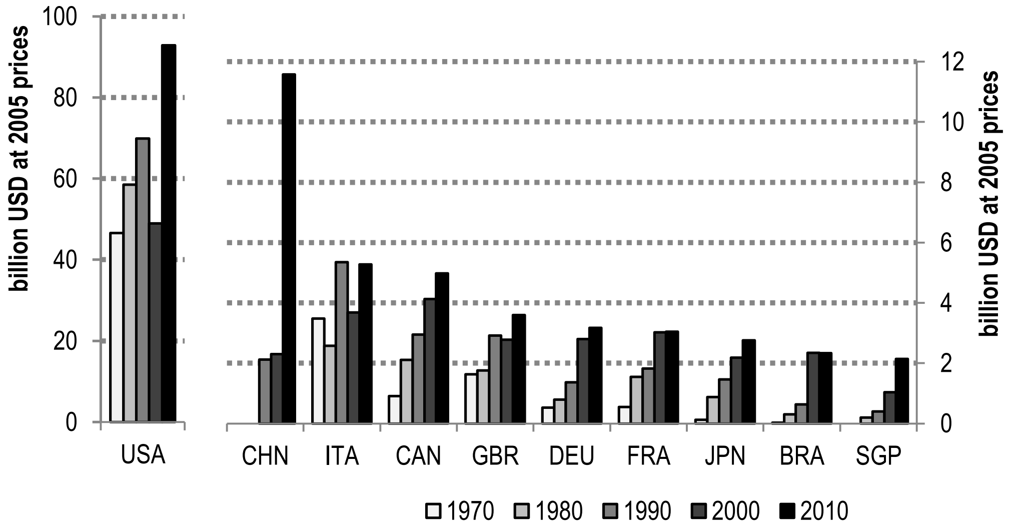


Source: UN Comtrade; WDI
Notes: Aircraft exports defined by ISIC Rev.3 codes 792 (excl. 7925), 7131, 714 and 87411;

Zooming in to the country level, comparing the list of the top 10 exporters (Figure 2.4) and the top 10 producers (Figure 2.5) offers interesting insights into the competitiveness of countries. The US is a leader both in terms of exports and value added. Four European countries, France, Germany, the UK and Italy feature among the top exporters as well as top producers, but their rank changes significantly if we consider value added rather than export value, which is affected by the strategy of internal collaboration and the pricing of intermediate and final products. Most striking is the second position of China among the top producers. Here we have to note that these figures may be exaggerated due to counting Chinese company's outputs based on their main industrial activity, and also including military production. Nevertheless, most of these products are for domestic use, China is yet to establish itself as a major aircraft exporter. The other countries appearing on both top lists, Canada, Brazil, Japan and Singapore each have a competitive edge in some segments of the industry. Canada owes to its regional jet and engine industries, Brazil to the regional jets, Japan and Singapore to parts and components manufacturing and its position as an MRO, warehouse and logistics provider.

DOI: 10.14267/phd.2016013

Figure 2.5 The 10 largest aerospace producer countries by value added, 1970-2010



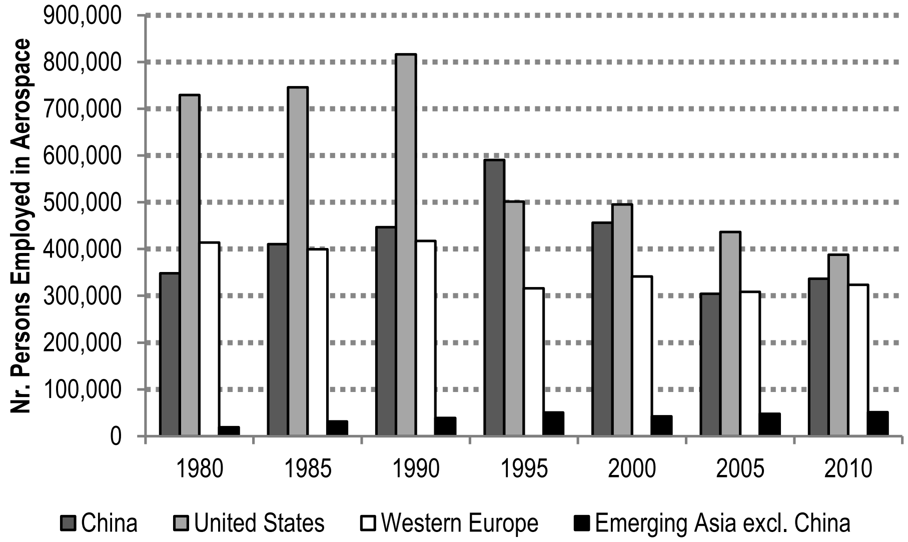
Source: OECD, EUKLEMS, Eurostat, UNIDO, National statistical offices; WDI.
Notes: Aerospace includes aircraft and spacecraft manufacturing

The most striking trend that affected the evolution of global aerospace employment, the drastic cut in US aerospace jobs, was already discussed in this chapter. The question that remains to be addressed is whether these jobs "migrated" to other countries, or were lost or migrated to other sectors. Roughly counting (that is, not distinguishing the space segment and defense segments), 470 thousand jobs were lost globally between 1990 and 2011. North America and Europe lost even more than that, 480 aerospace jobs (with much of it affecting the US, aerospace employment in Europe has remained roughly stable since the mid-1990s) due to the cuts in military spending after the end of the Cold War and due to an overall consolidation of the industry. Only a fraction of these jobs were recovered elsewhere in the world, suggesting that fears in the industrialized countries may be exaggerated. As demonstrated by Figure 2.6, China, the second largest aerospace employer, followed a path of its own, and employment levels where shaped by internal dynamics rather than global trends. The growth in the early 1990s and the subsequent decline is most likely the outcome of a reshuffling of state-owned enterprises. Previously identified as numbered "machine building industries" with heterogeneous activities and at numerous locations across the country, the mostly military-oriented firms were regrouped in 1999 into two conglomerates, AVIC I and II. The process of consolidation that has yet to be finalized saw a gradual and limited opening to the market and the removal of only some of the duplication of activities, but

DOI: 10.14267/phd.2016013

complexities in ownership remain, according to the still limited information available on firm-level dynamics (Goldstein 2006, Eriksson 2011). The most recent years once again brought employment growth in China, but it is important to emphasize the persistent qualitative differences in the education and skills of labor force, making international comparison somewhat problematic. Elsewhere in Asia, aerospace employment has remained relatively small compared to Europe and North America, so considering the global developments, at least for now, the regional redistribution of employment has remained limited.

Figure 2.6 Trends in the global distribution of Aerospace jobs, 1980-2010



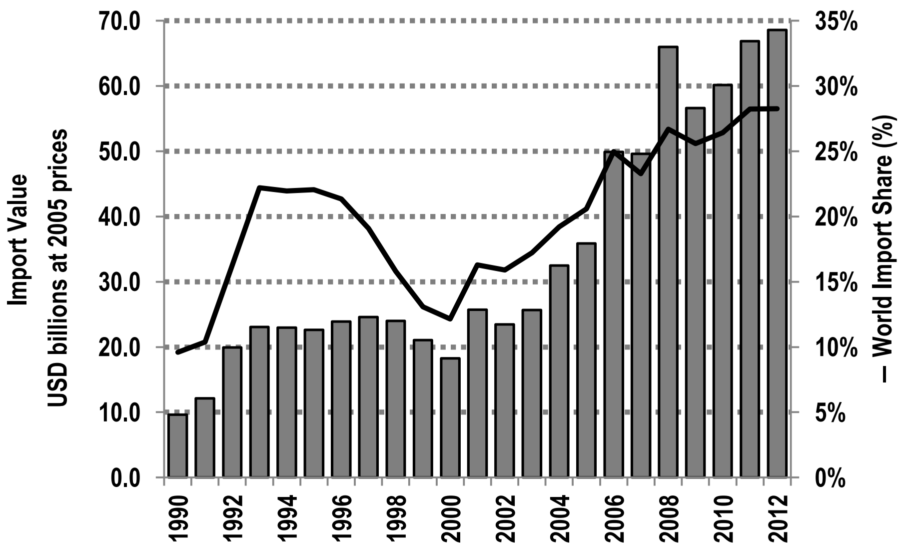
Source: EUKLEMS, Eurostat, OECD STAN, UNIDO, National statistical offices.
Notes: Aerospace includes aircraft and spacecraft manufacturing

To better understand the most recent trends in internationalization, one should take a closer look at the developments in emerging economies that are emerging as producers of aircraft or their parts. These, mostly Asian, but also Latin American countries are responsible for a rapidly growing share of global aircraft imports (more than one in four aircraft in value terms, as shown in Figure 2.7). Although, as we have seen above, their some 10% share in global output is relatively small, they show rapid growth through a new kind of export specialization. From many aspects, these countries show little commonality. Some, like Brazil and Mexico run a positive trade balance in aircraft, while others, such as Singapore, China, India, South Korea, Thailand, Malaysia or Turkey are net importers (Figure 2.8). Some of these countries have longer tradition in producing aircraft or parts (owing to Embraer in Brazil, ST Aerospace and other

DOI: 10.14267/phd.2016013

transnational companies in Singapore, military and civilian state-owned producers in China or IPTN/IAe in Indonesia) while others are relatively newcomers (such as Mexico or Malaysia). Production has so far not followed demand, but this imbalance provides ambitious governments with some leverage to gain access to technology and production capacity to force sellers to source at least some of the value of their aircraft from these countries. Yet changing the international division of labor in such a high-tech industry does not happen overnight, and depends on the successful implementation of policy and business strategies. These strategies show a common pattern, or a new wave of latecomer entry, which can be described as **entry to aircraft industry through the supply chain**.

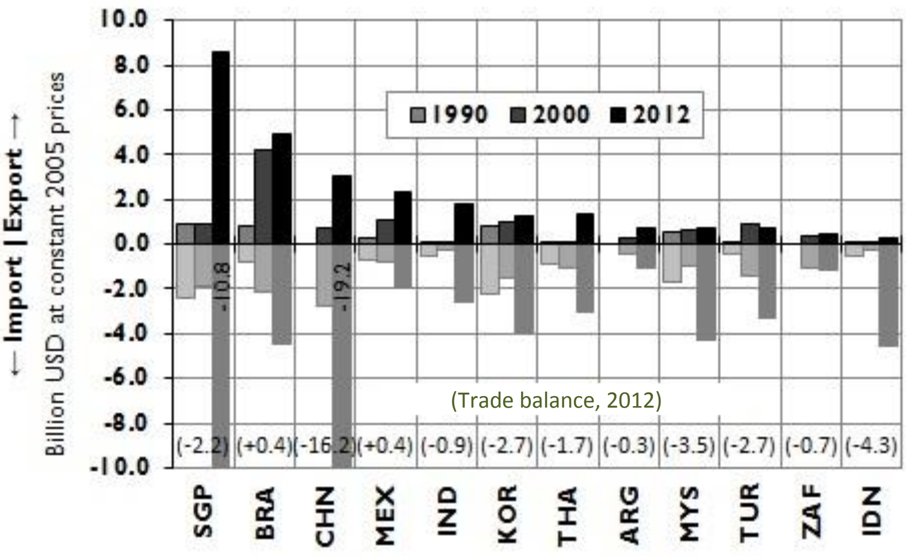
Figure 2.7 Aircraft imports of emerging economies



Source: UN Comtrade; WDI
Note: Aircraft industry defined by ISIC Rev.3 sectors: 792, 7131, 714 and 87411

DOI: 10.14267/phd.2016013

Figure 2.8 Balance of trade in aircraft for selected emerging economies



Source: UN Comtrade; WDI
Note: Aircraft exports defined by ISIC Rev.3 codes 792 (excl. 7925), 7131, 714 and 87411

At an era when companies are more and more producing goods and services through supply chains that span various countries, traditional trade statistics become less and less capable of measuring the contribution of each country to the total value of a good or service in the supply chain. Recent attempts by the OECD and the WTO tried to address this gap by compiling statistical data on the end use of exports (Zhu et al. 2013). Data on intermediate trade in aircraft offers interesting insights into ways countries become integrated in the global aircraft industry. Figure 2.9 shows **two distinct patterns**. One trading pattern is followed by a single country, Brazil, the only emerging market exporter specialized in assembling and selling entire aircraft. In fact, this corresponds to a strategy which we called the "first wave" of internationalization, or which is entry from the top of the supply chain for an "indigenous aircraft" developer and producer – a process in which Embraer of Brazil turned out to be more successful than most others (Eriksson 1995, Vertesy 2011).

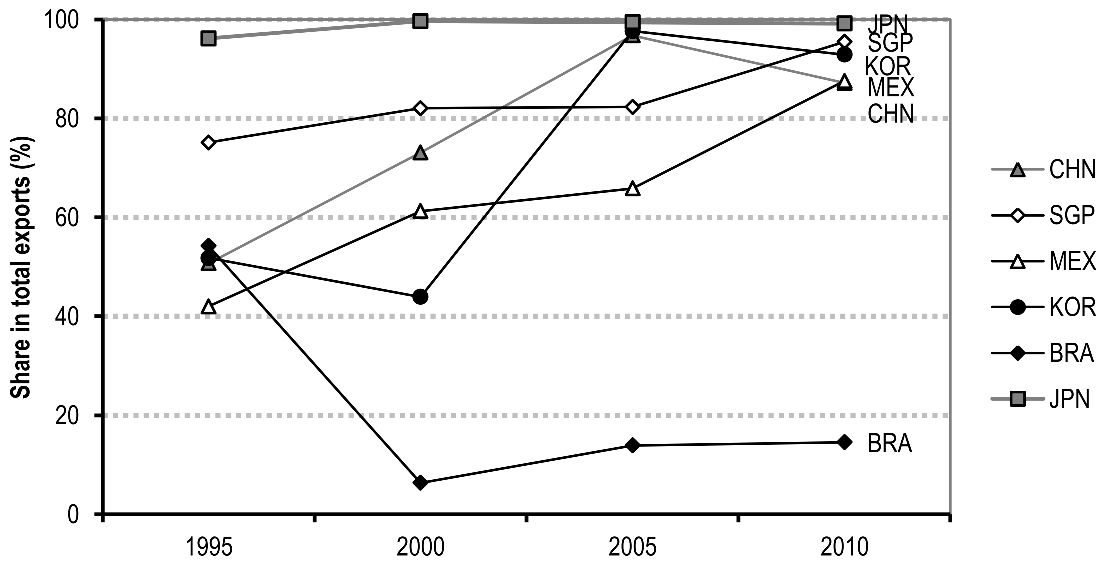
The other countries have become increasingly specialized as parts and component suppliers, among them China, South Korea or Mexico. They have done so following the model established by Japan, which, after a failed attempt to produce entire airliners (i.e. the YS-11 by Nihon consortium) shifted to parts and components manufacturing, and has become one of the leading suppliers of advanced composite materials[10]. Singapore

[10] For instance, Kawasaki, Fuji and Mitsubishi Heavy industries produce structural parts for the Boeing 787 *Dreamliner*.

DOI: 10.14267/phd.2016013

followed a similar strategy from the establishment of its aerospace industry in the 1970s, when, leaving behind its single role of an entrepot trading post, it has become a provider of MRO services and an important producer of parts and subsystems. This graph offers further explanations to the difference between the size of production and export of China: although it can sell aircraft in the domestic market, when it comes to exports, China's current strength lies in supplying parts and components. If China's other strategy, that is, indigenous aircraft development, comes to fruition and Comac succeeds in exporting the ARJ-21 or C-919 jets, this picture will change. In any case, as for now, Figure 2.9 indicates that most of the aircraft-industry exports (more than 80% in 2010) of China as well as the selected countries are used as intermediate goods by producers in their partner countries.

Figure 2.9 Share of intermediate goods in aircraft exports of selected countries



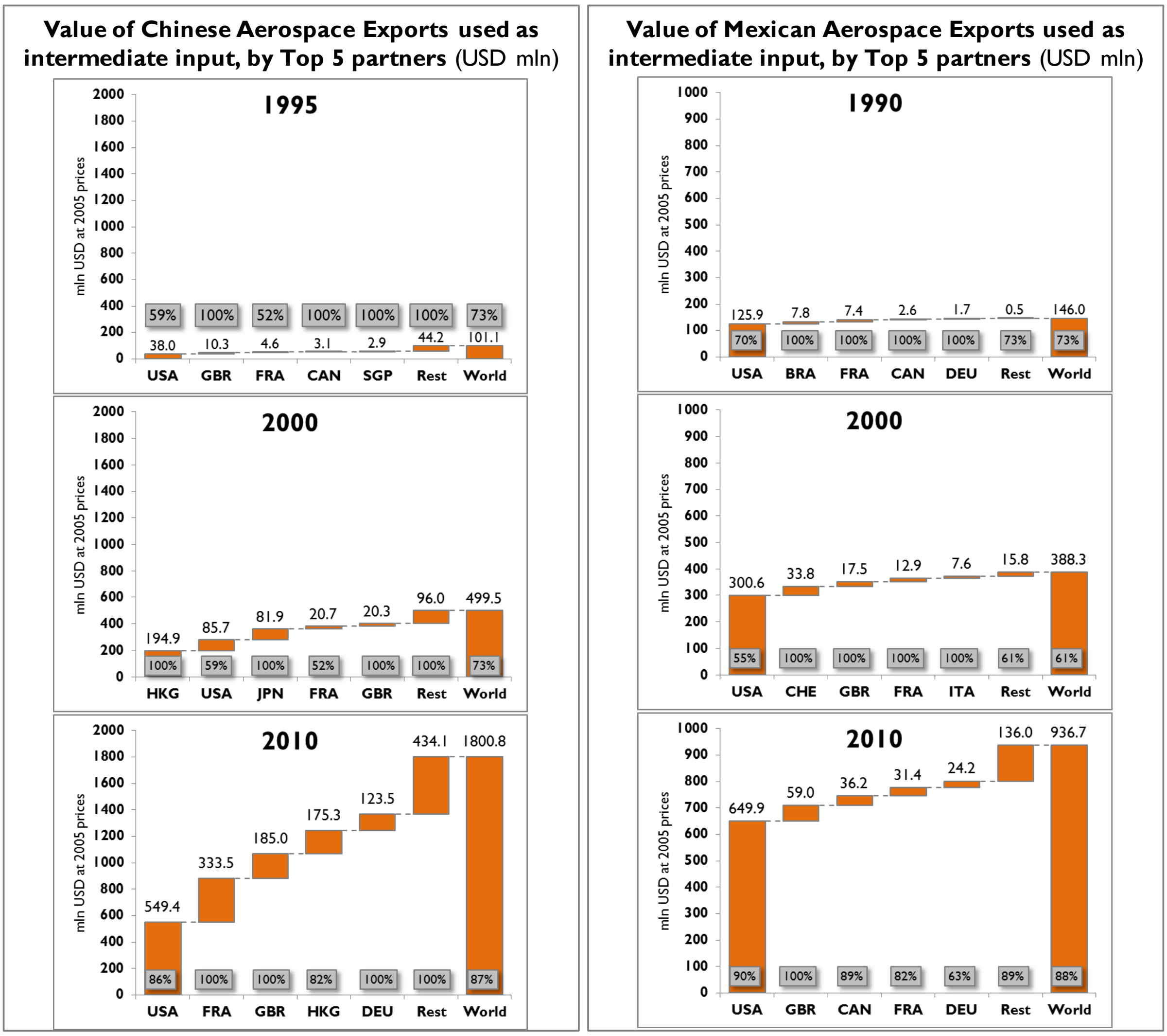
Source: OECD STAN Bilateral Trade by End Use database,
Note: Values refer to entire aerospace industry

Yet, there are important differences between how countries of this latter group have integrated in global supply chains. Figure 2.10 offers more details on the structure of intermediate exports of two selected countries, China and Mexico. It distinguishes the five largest foreign users of their aircraft industry products, and looks at their evolution over time. In the case of China, we see a slower start, yet a more balanced geographic distribution: only after the year 2000 did the process of integration into global supply chains take off, but intermediate exports grew rapidly in the following decade, and its

DOI: 10.14267/phd.2016013

customers include US and European producers. Mexican aerospace exports to the US amounted to 300 million USD already in 2000 – owing, to some extent, to the establishment of NAFTA. This further doubled by 2010, but the US still remained the dominant trading partner.

Figure 2.10 Evidence of latecomer entry through the supply chain



Source: OECD STAN Bilateral Trade by End Use database; WDI
Note: Values refer to entire aerospace industry. The % values in boxes show the share of intermediate products in selected export relations.

2.3 The limits to internationalization

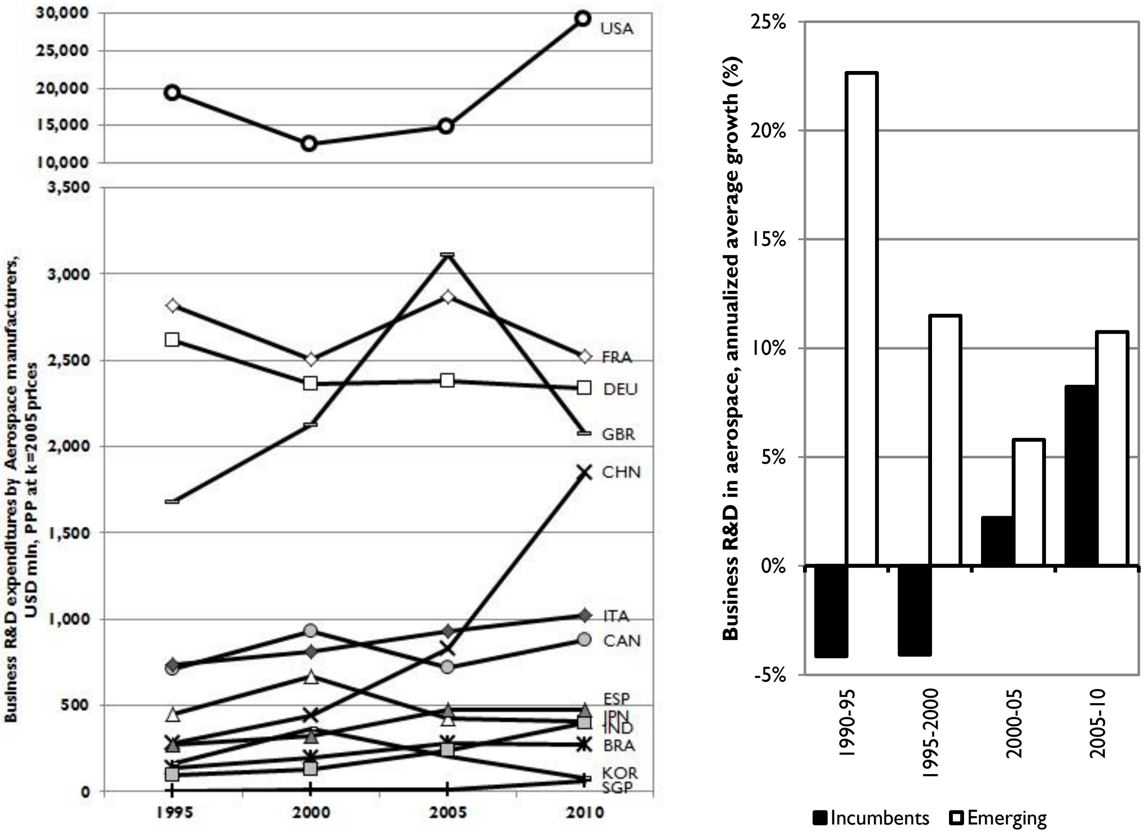
The relatively slower speed of internationalization of the aircraft industry compared to others can be attributed to a number of economic and political factors. First of all, new entrant companies cannot gain competitiveness overnight, but through the outcome of a longer learning process. This depends on joint efforts done by the company as well as the host governments, by establishing a learning and innovation system, with the provision of specialized human resources, the availability of education, training and research institutes and the availability of linkages to other industries and leading producers. The provision of specialized labour force is crucial (Niosi 2005). Establishing stand-alone institutes is not enough as long as there is a lack of interactions (flow of finance, skilled human resources, ideas, products, etc.) between the key actors of the innovation system (Vertesy, 2011). Second, if the high costs of continuously financing these efforts were not a big enough barrier of entry, latecomers have to reach markets limited by strong standards and political obstacles. The more complex activities latecomers aim for (i.e., an entire aircraft), the higher obstacles they face. At the same time, posing political obstacles is a double-edged sword, as latecomers can also trade market access to foreign producers for access to technology and localizing higher value-added production activities. It also needs to be emphasized that developing and manufacturing a modern aircraft are extremely complex processes, and so is optimizing supply chains, thus any decisions that are made are affecting the life-cycle of an entire aircraft programme.

Third, scale economics favour established trading patterns, and at least in short and medium term, it is much cheaper to buy aircraft and their components rather than make them. To a similar degree, the returns to R&D spent by incumbents is expected to be higher than to recent entrants, making a race against a target that is moving away faster. The largest aerospace R&D spenders happen to be incumbents: the United States, France, Germany and the United Kingdom (see the left panel of Figure 2.11). US companies are by far the largest aerospace R&D spenders; they spend far more than those of the next ten countries combined. It has to be underlined that even if reported figures include military and space R&D, their outcomes are important sources of new technology used in commercial aircraft. But the R&D landscape has also seen important recent changes. China is emerging as a new major aerospace R&D spender as well as an employer of scientists and engineers. At some distance, India has also increased its aerospace research spending (on its part, this concerns mostly the space sector), and so have Singapore and Brazil. As the right panel of Figure 2.11 demonstrates, the growth of R&D expenditure by emerging aircraft producers has outperformed that of incumbents by some 3 percentage points a year since the year 2000. Direct or indirect public support plays a crucial role in these developments, and in fact a number of

DOI: 10.14267/phd.2016013

American and European companies have made strategic attempts to benefit from these programs. The emergence of world class R&D capacity beyond the traditional locations, and the "competition" by governments to support them also increases the pool of available risk-sharing partners for incumbent system integrators, which will further increase international specialization along the supply chain.

Figure 2.11 Evolution of Business R&D expenditures by aerospace manufacturers in selected economies



Source: OECD, National statistical offices;
Notes: Emerging producers include Brazil, China, India, Mexico, Singapore and South Korea. Available data does not allow for distinction between civilian and military R&D.

2.4 Two waves of internationalization

In this chapter we have seen that internationalization has characterized the aircraft industry for many decades, but has accelerated in the last 20 years. The direction of internationalization and its driving mechanisms have also changed. International trade in aircraft has intensified, and the reliance on global supply chains is the reality in today's commercial aircraft industry.

DOI: 10.14267/phd.2016013

These findings confirm and complement earlier studies on the internationalization of the sector. Mowery and Rosenberg (1989) explained how the process took off at the end of the 1970s due to a confluence of changes in policies, market conditions and technology. Deregulation in the US air transport services sector, the erosion of the government's funding of (primarily military) research and development (R&D) which was essential for establishing US dominance in the industry, the decline in the commonality of military and commercial technology, the increasing technological complexity and the increasing development costs all contributed to increased financial risks for companies. Furthermore, the market share of the US in new aircraft started to decline, making foreign sales crucial for financial success of US producers, spurring international collaboration. By the 1990s, as Golich (1992) pointed out, collaboration of former national champion enterprises had become the only means of survival in an industry characterized by high risks and costs associated with R&D and production, long investment cycles which had increased 2-3-fold to 10-15 years since the end of World War II, and features of the market it served, in which – apart from a product's price, performance and on-time delivery –, politics played a key role for competitiveness. Eriksson (1995) surveyed the sector in a number of newly industrialized economies and emphasized the increased importance of East and Southeast Asia in the global aircraft industry. Niosi and Zhegu (2005) highlighted that the main steps in the internationalization process following the initial period of the USA's supremacy were Europe's catch-up in the 1970s and 80s and the emergence of the duopolistic war between Airbus and Boeing, and eventually the worldwide diffusion of the industry. The state of the industry today is characterized by concentration, competition and also collaboration in R&D, while new countries are becoming part of the international aircraft supply chain. Esposito (2004) showed that the evolution and intensification of international collaborations in commercial and military aircraft and engines has been a gradual process which began with collaboration agreements initiated by engine makers, and continued through the creation of the European Airbus consortia which was building on lessons from the *Concorde* project, evolving into a complex web of global cooperation. Hagedoorn (2002) offered further evidence that international R&D partnering in the aerospace and defence industry increased substantially by the 1990s, in contrast with that of previous three decades, and in that decade in particular, also in contrast with other high-tech industries. With regards to the more recent trends, authors point out that new countries beyond the US-Europe core are entering the

DOI: 10.14267/phd.2016013

industry through the supply chain; i.e. China emerged as an international parts and components supplier, applying its strong bargaining power to offer market access (Eriksson 1995, Goldstein 2006, Eriksson 2011).

With a certain degree of abstraction, we argue that internationalization of the industry in the past half a century happened in **two waves**. What began with the intensification of collaboration between producers that vertically integrated the capacity to design and produce aircraft, internationalization through joint ventures for R&D collaboration, company spinoffs, mergers and acquisitions reshaped the industry in a way that today's producers are mostly specialized in a few activities along the supply chain. In the multi-tier structured industry, the largest aerospace (and defence) producers may be competitors at some level in certain products, while collaborating in others, for instance, as risk-sharing partners in components and subsystems. Even for the US, where many of the collaborating partners are domestic, the trend observed by Craypo and Wilkinson (2011) on Boeing jetliners is rather telling: while only 2% of the B-707, a product of the 1960s, was produced outside the US, this share was 30% for the B-777 of the 1990s; we now see that around 65% of the latest B-787 *Dreamliner* airframe relies on foreign suppliers[11].

This first wave of internationalization, which began in the 1960s and ended with a major shakeout and consolidation in the 1990s, typically occurred between incumbent countries and firms of the North America, Europe and Japan triad. More recently, a second wave of aerospace internationalization emerges, distinguishing itself from the first wave. Whereas the first one saw the set of aerospace producing countries largely unchanged, this new wave sees a global expansion of the industry. This expansion has many underlying reasons – structural, political and economic. The new structure of the industry that crystallized by the end of the 1990s is more favourable for new entrants. While those latecomers that made attempts to join the industry after World War II often faced insurmountable technological and capital barriers when they tried to launch mega-projects and establish (copying incumbents) the entire vertical spectrum of aerospace production. It is hardly surprising that many of these attempts – from Argentina to Indonesia, and even China – failed to deliver the ultimate goal, the serial production of

[11] Peterson, K., 2011. Special Report: A wing and a prayer: outsourcing at Boeing. *Reuters*, 20 January, <URL: http://www.reuters.com/article/2011/01/20/us-boeing-dreamliner-idUSTRE70J2UX20110120>

DOI: 10.14267/phd.2016013

indigenous aircraft; or, if succeeded, were short lived (Eriksson 1995, Vertesy 2011).[12] Yet, both the technological and capital barriers of entry are significantly lowered when a new entrant climbs gradually along the supply chain. From Mexico (Martinez-Romero, 2013) to China and South East Asia, we see new producers that specialize in supplying high quality, high tech components for major system assemblers such as Boeing and Airbus. Produce and innovate, as observed in many other high-tech industries (Kim 1997, Amsden 2001, Hobday 1995). This results in less visible, grand scale projects, but is probably economically more sustainable.[13]

The world order after the end of the Cold War became multipolar, in the economic and political sense (Wade 2011). Establishing aerospace production (and innovation) capabilities is seen in this context as a contributing factor for high-tech competitiveness, and a strategic aim for many emerging economies (BRIC countries as well as others) that aim at increasing their regional or global influence. Given that airlines in these countries are often in state hands, they can strategically trade with market access in exchange for access to technology, often in the form of offset agreements. On the one hand, high economic growth and demand for transportation go hand in hand, thus the growing demand for new aircraft gives strong leverage for emerging economies. On the other hand, incumbent parts and component suppliers also see potential in capitalizing on the growth outside their home territories, and are ready to invest even if it takes longer to recover their investments, and even if they are forced to enter joint ventures in partnership with receiving governments.

The second wave of internationalization is driven by transnational corporations, which integrate design and engineering, manufacturing, distribution and after-sales support activities in multiple locations around the (Aerostrategy 2009). On the receiving end, governments increasingly compete to attract firms in the supply chain, by establishing aerospace business parks, providing tax breaks and even supporting R&D. Table 2.3 summarizes the distinctive features we attributed to the two waves of internationalization.

[12] Of course, the reasons why only Embraer of Brazil succeeded in becoming a successful exporter of commercial aircraft already in the 1970s and 80s is far more complex than structural, see (Ramamurti 1987, Frischtak 1992, Cassiolato et al. 2002, Goldstein 2002, Marques 2004, Vertesy 2011).

[13] China is a special case here. Although producers from the country have made more successful inroads into the industry through the supply chain than in previous attempts for indigenous innovation in previous decades, the government in parallel is also pushing large-scale aircraft development programs – see the ARJ-21 and the C-919 projects. But the choice to include in these aircraft components designed by incumbent (foreign) suppliers shows a strategy of simultaneously gaining competence at all levels of the supply chain.

DOI: 10.14267/phd.2016013

Table 2.3 Characteristics of the two waves of internationalization in the aircraft industry

	First Wave	**Second Wave**
Years	1950s-1970s	1990s-
Industrial organization	characterized by vertically integrated companies	multi-tier, pyramid structure, presence of global supply chains
internationalization driven by	host governments in emerging economies	incumbent firms + host governments in emerging economies
new entrant's goal	establish vertically integrated companies (expertise in all activities); national security interests	establish specialized companies (expertise in a certain system or component); move up along the supply chain; national security interests
incumbent's strategy	defend technology and markets	collaborate to reduce costs; access to growth markets
new entrant's dominant trade policy	protectionist	strategically protectionist; within limits
incumbent's dominant trade policy	protectionist	strategically protectionist; within limits
Limits to internationalization	high technology and investment barriers	lower technology and investment barriers
Late entrant cases	Brazil; Argentina; Indonesia; China	Japan; Singapore; South Korea; Mexico; China
technology market	restricted	global
product market	global	global

Source: author's compilations

2.5 Conclusion

To conclude our empirical chapter, we found that the global commercial aircraft industry has veen undergoing a major transformation. The market for new aircraft and their maintenance has become truly global, driven to a large extent by the particularly strong demand by airlines in East Asia and in the Persian Gulf. Still today, despite significant attempts made by governments around the world, the aircraft industry is not as internationalized as other high-tech sectors. The large majority of commercial aircraft families are designed and also produced in America and Europe, as shown by production and export statistics. We can already observe turbulence in the aircraft manufacturing industry, a slow but profound change as the industry expands towards East Asia. Strong aerospace clusters have emerged from Singapore to Shanghai, Xian and Chengdu, Shenyang and Harbin in China, in South Korea, and are emerging in India and Malaysia, while Mexico is on the rise in Latin America. These new production centres are creating real competition for incumbent producers.

DOI: 10.14267/phd.2016013

Over the past half a century, new entrants to the aircraft industry tried two distinct strategies. The first one aimed at achieving the capacity of indigenous aircraft design. This strategy, pursued over from the 1960s to the early 1990s failed to produce commercially successful aircraft, despite the huge investments made by Japan, China and Indonesia. An exception was the market-niche oriented Embraer of Brazil.

Another strategy was to build up the technological capability to produce parts and components, assemble aircraft under licence or attract leading producers, by applying a variety of economic and political means. This latter strategy was first introduced by Japan in the 1980s, and was followed by many after the end of the Cold War, proved to be more successful for new entrants. Apart from following the technologically less demanding bottom-up approach, the other reason of success was the right timing. Entering at a time when incumbent producers of industrialized countries were forced to rationalize costs and when new information and communication technologies shrank distances, access to the market was easier. This way, by further deepening mutual dependence, new entrants could gain a foothold in an industry otherwise protected by high barriers of entry. The interplay of these developments, which we proposed to call the "second wave of internationalization", triggered a substantial reorganization of the entire global aerospace industry, the end of which process we are yet to see in the upcoming decades. Nevertheless, statistics on the end-use of exports already shows how countries have specialized along the supply chain as intermediate exporters.

As in the case of all abstractions, the world is more complex and countries tend to follow a mix of these strategy. For instance, while attracting leading companies of all tiers to produce locally, China also strives to design and manufacture "indigenous" aircraft (the ARJ-21 and the C-919), which would typically be the hallmark of a "first-wave" strategy. Considering on the one hand the serious delays in receiving international airworthiness certification for both of these programmes, and the advances made by establishing final assembly lines and component manufacturing centres for leading global producers, we see that, at least for now, the advantages of the 'second wave' strategy are more tangible. But needless to say, in a country the size of China and with declared regional security goals, the motivations for selecting strategies go beyond what concerns the commercial segment of the aircraft industry. But as technology complexity, capital intensity, and the long lead time of product development continue to pose significant barriers of entry to this industry, all countries try to exploit political influence to support the industry so strategies vary. Clearly, a fierce battle is fought for

DOI: 10.14267/phd.2016013

every percent of market share, and gaining and sustaining competitiveness depends on many more aspects, as also shown in other chapters of this book.

Production data shows that the United States remains the towering leader in aircraft manufacturing. Fears of North America losing positions are therefore exaggerated. It is evident that the US maintains its strong competitiveness partly while gradually reducing aerospace jobs, a process underway since the early 1990s. There is however little evidence on whether these jobs would go to other parts of the world; we observe a general reduction of employment in the sector due to consolidation and possibly efficiency gains due to information and communication technologies. Countries of Western Europe have managed to maintain a relatively larger share of aerospace jobs while increasing exports, but in terms of total output, they face stronger competition from Asia. A future change in competitiveness could also be expected in light of the significant increases in aerospace R&D spending in China, India and other Asian countries.

It is also important to emphasize that the trends are somewhat blurred by the influence of the military and space industry segments and the difficulty to distinguish them in official statistics. For instance, while commercial demand is mostly shaped by business cycles, military orders continue to play a crucial role in supporting new product development, and are an important driver of internationalization of the industry and public procurements may cushion against the effect of crises. However, if military orders become excessive, they also have the potential of reversing the waves and shifting back from globally distributed supply chains to greater domestic concentration. This is a future scenario that one cannot exclude. Another future scenario to consider is linked to the fate of the particularly strong current demand for new aircraft. In the wake of the recent financial crisis, demand for new aircraft did not decline to the same degree as would be expected considering the effect of previous macroeconomic cycles on the industry. On the contrary, new orders for more economic new aircraft have created what some industry analysts see as a bubble that may burst, having particularly strong impact on all producers.

DOI: 10.14267/phd.2016013

Chapter 3: Literature on Catch-up, Schumpeterian dynamics and Innovation

3.1 Introduction

This section provides an overview of the literature on latecomer industrialization, technological capabilities and innovation systems. Its purpose is to identify the main theoretical foundations for a framework of analysis of latecomer industrialization in aerospace.

The literature review starts in section 2.2 with the old problem of technological learning and latecomer industrialization. The basic question that was raised: *is there an advantage in being a latecomer*? According to the Gerschenkronian tradition, being a latecomer country holds a potential. First movers have to pay the price of developing a new technology, test its applicability in practice, while latecomers can readily take the results and avoid the first movers' costs. As many examples from East Asia have shown, latecomers with lower production costs can indeed gain large market shares. But historical experience also shows that acquiring technology is not automatic, and is more than simply following a pre-written recipe. The second strand of literature we look at addresses the difficulties in accumulating *technological capabilities* and some of the actual disadvantages of latecomers (section 2.3). Many authors devised stage models to highlight the progress of technological learning in a variety of industries. The appropriateness of stage models for the analysis of latecomer aerospace innovation is examined in section 2.4. The following section (2.5) discusses the systems of innovation approach from a dynamic perspective. Section 2.6 provides a survey of the existing literature on innovation, technological change and economic growth in the aerospace industry both in countries at the technological frontier and in developing economies. Section 2.7 looks at another body of existing works. Here we focus on technological development in aerospace, which helps the reader better understand the "big picture", the major trends of technological change at the frontier since the 1950s. The summarizing section 2.8 provides an overview of the main conclusions of the literature review and highlights the questions so far unanswered.

DOI: 10.14267/phd.2016013

3.2 Latecomer advantages and how to benefit from them

The idea that economic backwardness may be an asset for latecomer industrialization has been at the center of debates on economic development. Building on the work of Veblen (1919)[14], Gerschenkron (1962) argued that the more economically backward a country is, the greater "the opportunities inherent in industrialization" are. The idea behind this is that technologically backward countries can potentially apply existing technologies at much lower costs than the countries that developed them. Catch-up at the country level occurs as productivity increases due to more advanced technology and the per capita income difference narrows between leaders and followers. The larger the initial productivity gap (or the greater the distance to the technological frontier), the greater is the potential for growth. This happens because latecomers can enter directly into large-scale production in the most dynamic industries and take advantage of their lack of institutional inertia. The tension between the "great promise" of economic development demonstrated by the leading countries and the reality of stagnation is an important motivating factor for institutional change in the follower. However, due to institutional obstacles catch up cannot occur (such an obstacle was serfdom in Russia or the lack of political unity in Germany). In the 19th century, in industrializing Russia state intervention compensated for (or substituted) the insufficient (or inadequate) physical, human and technological resources required to catch-up. Establishing appropriate institutions and organizations are crucial for the successful *substitution* of missing prerequisites. In Gerschenkron's examples these functions were provided by development banks in France, universal banks in Germany and government investment in infrastructure in Russia in the late 19th century.[15]

The rapid development of many East Asian economies in the second half of the twentieth century (Hong Kong, Singapore, South Korea or Taiwan) testifies to the possibility of reaping latecomer advantages, providing evidence of dynamic developments at firm and sectoral levels in industries such as automobiles, electronics and semiconductors (Kim 1980, 1997, 1998; Kim and Nelson 2000; Fagerberg 2000; Hobday 1995, 2003; Amsden 1989, 2001; Mathews 2002; Westphal 2002). In a broader context, it was found that accelerated growth is achievable with latecomer

[14] It should be noted that Veblen's view was in many ways sharply different from Gerschonkron's thesis, e.g. considering technology transfer as a more automatic mechanism possibly driven by market forces. (c.f. Fagerberg 2005)

[15] Another often cited example from post-World War II Japan is the Ministry of International Trade and Industry (MITI).

DOI: 10.14267/phd.2016013

industrialization. Fagerberg and Verspagen (1999) empirically showed that manufacturing had been an engine of growth in the late industrialization of East Asia and Latin America. Szirmai (2005, 2011) concluded that no developing country achieved successful economic development without industrialization.

Gerschenkron underlined the importance of removing institutional obstacles and establishing institutions and organizations to realize latecomer advantages. Latecomer firms actually also face some significant disadvantages. According to Hobday (1995), they are dislocated from technology sources as well as from advanced markets.[16] It has remained a central problem in the literature on latecomer industrialization to identify the role of state and private actors in starting and carrying out the institutional changes, which can address these disadvantages. The same historical development paths of East Asian countries have been interpreted in very different ways depending on the spectacles observers were looking through. On the one hand, according to the neoliberal view summarized in a widely cited World Bank (1993) report ‘The East Asian Miracle’, the success of governments was their ability to provide a stable macroeconomic environment and to follow market-friendly policies. This entailed limited inflation, only limited appreciation of real effective exchange rate, only brief periods of import substitution industrialization, and earnings from exports motivating technological upgrading in trading sectors. Additionally, public measures were concerned with human capital formation, establishing openness to international trade and a strong bureaucracy that relied on contests when making selective supporting measures.

On the other hand, both sectoral level and macro level studies (Amsden 1989, 2001; Chang 1993; Hobday 2003; Wade 1990) found historical evidence of strong state intervention. Amsden (2001) showed that “getting the control mechanisms right” was the key to the successful “Rise of the Rest”. Recently Chang (2003) and Cimoli *et al* (2009) have further argued (along the lines of Gerschenkron) that no backward country has ever developed without a relatively high degree of government intervention to facilitate technological accumulation and change the organization of production. Reinert (2009) showed how protecting infant industries in areas at the forefront of technological progress helped latecomers emulate the richer leaders of their time and reduce the

[16] On the other hand, Mathews (2002, 2006) optimistically argued that latecomer firms are not bound by organizational inertia. This allows them to shift quickly from being imitators to innovators, by benefiting of the ‘3 Ls’: linkage, leverage, learning in the age of globalization, which enhances their dynamic capabilities. (*Linking* up to global value chains, offering lower costs and gaining access to knowledge, technology, or markets. The gains exceed their inputs, offering firms greater *leverage*. As they do this strategy in a sustained way, they *learn*.)

DOI: 10.14267/phd.2016013

asymmetries in knowledge and technological capabilities, and made technology transfer profitable. Only after some measure of parity is achieved could partners specialize and trade according to their comparative advantages and could (neo-) colonialist structures be prevented. This reconfirms the theses of Friedrich List presented most notably in his 1841 volume ‘The National System of Political Economy’. List also argued that latecomers need protectionist measures to raise infant industries and new competitors, because free trade hampered progress by freezing existing trading structure.[17]

As latecomer industries mature over time, the need for interventions and the nature of interventions change as well.[18] Gerschenkron interpreted the “the gradual diminution of backwardness” (infrastructural development and industrial growth) with the redefinition of the relationships between the German industry and development banks on the one hand and between the Russian state and the industry on the other hand. German enterprises were increasingly collaborating with a number of banks (including banks they established) as opposed to being subjected to one single bank. Following a reduction of state intervention in Russia, universal banks emerged to take on long-run investment financing. Notice that while the backwardness of a country was being reduced gradually, the change of interventions was not similarly gradual. On the contrary, state intervention in Russia at the turn of the 20th century was reduced radically amidst depression and social unrest, as Gerschenkron presented it, but growth only followed after years of interruption.

It clearly remains puzzle for policy design how to deal with similar transitions. Lall (2004) argued that there is no uniform way. Intervention (industrial policies) needs to be *selective*, since learning depends on the complexity of technology, on the availability of information and extent of externalities. At the same time, policies need to learn as well. For the case of contemporary China, Gu and Lundvall (2006) showed how policy learning co-evolved with the development of industries. It is a question when interventions should be phased out or reduced.

---

[17] *“Any nation which by means of protective duties and restrictions on navigation has raised her manufacturing power and her navigation to such a degree of development that no other nation can sustain free competition with her, can do nothing wiser than to throw away these ladders of her greatness, to preach to other nations the benefits of free trade, and to declare in penitent tones that she has hitherto wandered in the paths of error, and has now for the first time succeeded in discovering the truth.”* (List 1841, Book 4, Ch.33, English translation by S.S. Lloyd, 1885.)

[18] The idea that infant industries can be protected as long as it is temporary has long been accepted by classical economist thinkers, such as J.S. Mill (quoted by Lall 2004, note 20). Neoclassical economics argues that protection is not justified anymore when a decrease in the long-term average costs causes no more losses for producers. Theory leaves the question open how to manage the transition from a state of protection to a state of no protection.

DOI: 10.14267/phd.2016013

The underlying assumption behind these arguments for protectionism is a dynamic understanding of competitiveness, which involves the possibility for latecomers to accumulate the technological capabilities that more advanced producing countries are applying are applying. Before entering into a more detailed discussion of the literature on technological capabilities in section 3.3, we make a detour to address an often neglected question with regard to latecomer entry.

3.2.1 The timing of latecomer entry

Does the timing of entry into a new industry matter? There are three reasons why timing matters. First, the nature of competition and characteristics of innovation varies over an industry's life cycle (Abernathy and Utterback 1978; Utterback and Abernathy 1975; Gort and Klepper 1982; Malerba and Orsenigo 1996a; Klepper 1996, 1997). In these models, barriers to entry are usually lower at the initial phases of an industry's development, but there is uncertainty about market demand and potentials of technological improvements. Despite the easier access, companies in developing countries with lower levels of technological capabilities face a disadvantage, because the codification of technology is low at this 'fluid' early stage. High capital and technological entry barriers keep firms from developing countries away from entering at an early stage. On the other hand, when a dominant design has emerged and the industry is more consolidated, high concentration of powerful market actors can virtually impede new entry. In spite of this, successful latecomers from emerging economies have usually entered the industry in the mature phase. Hobday (1995) showed how latecomer firms made use of the price competition during latter stages by focusing on process innovation as opposed to product innovation. Perez and Soete (1988) brought this idea further by suggesting that rather than looking implications of life-cycles of products seen as independent radical innovations, technological paradigms should be the guiding posts for identifying "windows of opportunities" for latecomers. Latecomers that developed capabilities to produce products according to a previous paradigm will at a later point have to pay the price of unlearning vintage technologies and re-learning new ones. They can, however, take advantages of learning while everybody else is learning and entering while the threshold is lower at the onset of a new paradigm. The authors acknowledge that a certain level of existing knowledge and resources are necessary to make use of the

DOI: 10.14267/phd.2016013

opportunities. This suggests that the question is two-fold: timing may matter not only with regards to entry, but also with regards to responding fast to a changing paradigm and redefining the growth trajectory.

Second, similar windows of opportunities may exist from an institutional point of view. Timing, we argue, matters because the global political landscape and international trade regimes changed over time and as do the volume and pattern of international trade. All these changes influence the potential of firms to access technology and information as well as the channels through which they can learn. With the emergence of the regulation on tariff and non-tariff barriers, intellectual property rights and new quality standards, technological learning of firms from developing countries has changed significantly even over the last fifty years. In short, countries starting the catch-up process now face a different environment than those starting in the fifties and sixties.

Finally, in light of these changes the ability of governments to devise and implement supportive policies has also been changing. The volume of trade realized within different units of transnational corporations has increased exponentially (UNCTAD 1997, 2009). The significance of borders is clearly diminishing. International political scientists have highlighted a power shift from central governments to a variety of domestic and foreign social and economic actors (Mathews 1997). Both political and economic developments increased the interdependencies between all these actors have increased, which in turn also increased the complexity of governance tasks (i.e. Rosenau 1997; Simai 1994; Skolnikoff 1993). Yet, at the same time governments have new tools to tackle the increased challenges. For instance, the diffusion of information and communication technologies (ICTs) offers a greater potential to oversee cross-border factor flows and achieve governance outcomes more efficiently (OECD 2003). We conclude that the broader political economic context in which catch-up latecomer industrialization takes place potentially affects its course and pace.

3.3 Technological capabilities

The Gerschenkronian growth potential notwithstanding, the economic backwardness of latecomers is a source of disadvantages in terms of capabilities. Leading producers can already benefit from scale economies, have access to advanced markets, and also have the power to influence suppliers. They can do so because of their mastery of technologies. They have also mastered the knowledge of how to develop new, commercially applicable technologies that can sustain their leading position on the

DOI: 10.14267/phd.2016013

technological frontier. According to Ames and Rosenberg (1963), the lack of latecomers' *technological capabilities* gives them a disadvantage which may outweigh other potential advantages described earlier. Using empirical data on structural change and comparative levels of total factor productivity, Timmer (2000) showed that investments do not necessary lead to catch-up if they are not associated with the assimilation of more advanced technology. This proved the argument of Nelson and Pack (1999) that rapid development requires not only capital (including human capital) investment, but also learning about and learning to use new technologies, as well as entrepreneurship and innovation.

For neoclassical economists, technology was an exogenous resource, or 'manna from heaven', which producers could directly acquire and apply, 'transfer' from one country to another. In this simple and abstract scheme previous experience in the use or creation of technologies did not matter. However, seminal studies on the nature of knowledge and technology point out the tacit element of knowledge (Polanyi 1967), the importance of learning by doing (Arrow 1962) and of the historical and institutional embeddedness of technology (Rosenberg 1982). Consequently, if a latecomer producer decides to apply already existing machinery or methods of production, they not only have to invest in acquiring the machines and the training to operate them, but a 'receptive soil' is also required in order to assimilate the technologies. In contrast with the neoclassical view, evolutionary economics offers a 'learning-friendly' explanation of the processes the creation, assimilation of technology in economic processes (Nelson and Winter 1982; Dosi *et al.* 1988). The evolution of the concept of technological capabilities should be viewed against this changed intellectual context.

Abramovitz (1989) argued that the *realization* of the *potential* for catch-up in a latecomer depends on how advanced its 'social capabilities' are. Hence the difference in the age of technologies across countries will not lead to more rapid growth in the follower unless there is technical competence (educated human resources) as well as physical infrastructure and appropriate political, commercial, industrial and financial institutions. These are not static but change over time in an interactive way, should a technological opportunity arise. Several other authors have also attempted to specify the most important capabilities for catch-up. For Dahlman *et al.* (1987) technological development required production, investment and innovation capabilities. Hobday (1995) found production and innovation capabilities to be crucial for development. Cohen and Levinthal (1990) argued that firms' innovative capabilities are influenced by

DOI: 10.14267/phd.2016013

their ‘absorptive capacity’, the ability to evaluate, assimilate and apply knowledge that is new to them. Lall (1992) made a distinction between technological capabilities at the firm level and at the national level. At the firm level, successful commercial operation depends on investment, production and linkage capabilities, as well as on the national institutional environment and infrastructure. Development, or capability accumulation at the national level is the outcome of an interplay of national technological capabilities (physical investment, human capital and technological effort), incentives (macroeconomic or competitive and the efficiency of factor markets) and institutions (including market and non-market ones).

Bell and Pavitt (1993) distinguished technological capabilities from production capabilities at the firm level based on the resources used to produce industrial goods from those needed to generate and manage technological change.[19] In practice, however, such a distinction is less than straight-forward, but it may help recognize the need to investment into technology accumulation in developing countries. Archibugi and Coco (2005) acknowledged that at the macro level technological and production capabilities were interdependent. Nevertheless, they attempted to separate them in order to compare composite technological capabilities indicators of the World Economic Forum, UNDP, RAND and their own ArCo index. The rank correlation showed that although there was a general agreement on the main components of the indices, different methods of weighting and aggregation made a significant difference. Measurement is nevertheless important if it can provide an indicator for technology accumulation. Nevertheless, Bell (2006) pointed out that the time dimension of the accumulation process has remained under-researched.

As the concept of technological capabilities broadened in scope, it became more ambiguous. Fagerberg and Srholec (2008) applied factor analysis to identify the factors in overlapping ‘capability’ concepts to highlight four groups of indicators that matter most for economic development. Their results point to the importance of capabilities associated with innovation (“innovation system”) and governance.

[19] See also Dutrénit (2004) on capabilities accumulation over time in latecomer firms, or Romijn (1999) for an overview on the use of the technological capability concept, on capability building and its importance in economic development.

DOI: 10.14267/phd.2016013

3.3.1 *Technological capabilities, stage models, and their relevance for the aerospace industry*

It follows from the preceding argument that catch-up by latecomers is not possible without the accumulation of technological capabilities, which is a learning-intensive process. Gerschenkron already pointed out the role of locally existing technological knowledge, or, even more, innovative activities.[20] Lall (2001, 2004) argued that there is a potential for underinvestment in advancing capabilities in developing countries, because technological learning is risky and unpredictable. Learning only succeeds if firms do it deliberately, but firms possess imperfect information and knowledge about the technological alternatives from which they can choose. There are several domestic and foreign channels through which learning can take place (through interactions with customers, input suppliers, technology institutes, universities, consultants, competitors), as well as several levels within an organization or in an industry. Once a minimum level of know-how to perform industrial activities has been acquired, there are also different learning paths to follow, depending on how much firms invest in learning. In short, firms need to learn the process of learning. At the industry level, since firms do not operate in isolation, their interactions with their environment at various levels offer externalities of learning and capabilities accumulation. The outcome of capability accumulation at the firm level will be catch-up at the sectoral or national level.

Observers of the successful catch-up of latecomers to high-tech industries in Southeast Asia have pointed out commonalities in the various learning trajectories.[21] There is a rich literature on stage models that explain catch-up of successful latecomers by their ability to progressively reach technologically more advanced stages of production.

In the model of Kim (1980), South Korean firms first had to *implement* imported technologies before the scientific and engineering staff could *assimilate* them and acquired the capacity to *improve* them. Throughout this process, firms became increasingly competitive, although not without considerable government support in the early phases. The learning trajectory described by Dahlman et al (1987) runs from *production capabilities* through *investment capabilities* to *innovation capabilities*. Lall

[20] *"What makes it so difficult for an advanced country to appraise properly the industrialization policies of its less fortunate brethren is the fact that, in every instance of industrialization, imitation of the evolution in advanced countries appears in combination with different, indigenously determined element."* (Gerschenkron 1962, p.26)

[21] Some authors are debating whether policy makers and managers consciously followed pre-defined strategies or were merely experimenting (Hobday 2009).

DOI: 10.14267/phd.2016013

(1982) emphasized that industries progressed from *elementary* through *intermediate* to *advanced learning* capabilities. Hobday (1995, p.1185) has argued that progression is not necessarily linear, since research and development (R&D) may be undertaken at an early stage. Nevertheless, he found a general tendency of firms starting up *simple activities* systematically at an early stage and gradually accumulating capabilities to perform *complex* activities at a later stage. Chaminade and Vang (2008) argue that developing country ICT firms start with competing with *low-cost* products and advance to become *knowledge providers* in the global value chain. In this transition regional innovation systems play a crucial role.

We argue that these stage models are not applicable to the aerospace industry for two main reasons. First, they do not match the distinctive features of the sector. Aerospace manufacturing is highly technology- (Smith 2005) and capital intensive. New entrants face a very steep learning curve (Frischtak 1994). Access to technology for latecomers is limited by the very high entry costs, rather than through patents. The industry is characterized by imperfect competition, non-homogenous products and major economies of scale. Fixed initial development costs are extremely high (Beaudry 2001). To overcome private underinvestment in new technology, governments have to support manufacturers, either through launch subsidies, export subsidies, military procurement or market protection. Arguments of national security, prestige and expected spillovers[22] to downstream industries and services[23] and to other sectors of the economy serve as justification for government intervention. Governments can influence the sector through industrial, trade, higher education as well as science, technology and innovation policies. Intervention is also needed due to the severe demand fluctuations for aerospace products, closely correlated with fluctuations in global economic growth. Aerospace firms face cyclical changes in demand and recurrent crises within the lifetimes of their products.

Second, stage models are not applicable for aerospace because the sector's high quality requirements demand firms to possess advanced capabilities early on. The technological complexity of aerospace products is rather high in even simpler modules (Dosi *et al.* 2003; Hobday *et al.* 2005). There is a tradeoff between cost and quality at

[22] The measurement of spillover effects related to the aerospace industry is difficult, especially in emerging economies. In the case of the Swedish 'JAS Gripen' fighter program Eliasson (2010) applied a spillover multiplier and estimated that the social returns above the opportunity costs were at least 2.6 times greater than the original investment.

[23] Downstream industries and services include transport, telecommunications, navigation, media or earth observation, many of which also offer benefits for public bodies.

DOI: 10.14267/phd.2016013

the core of many stage models of catch-up. A cheaper but less reliable consumer electronics product can be sold in large numbers if the cost is low enough. This trade-off does not exist for aerospace products. Quality standards for firms entering the market, even at the lower end, are higher than in many other sectors, given that an aircraft or spacecraft is as reliable as its weakest component. Latecomer firms can only sell their products if they meet the high standards set by the global industry leaders. When producing under license for foreign system assemblers, component suppliers are meticulously screened by the buyers. In cases of domestic procurement governments have little room for relaxing product standards without jeopardizing public safety. The threshold level of production capabilities is thus very high. Consequently, what would be categorized as a basic stage in terms of development in the stage models presented above in fact show characteristics of more advanced stages. Both the acquiring of threshold level production capabilities as well as sustained further growth require intensive investment capabilities, advanced technological learning in related fields, and (at least new to the country) innovation on behalf of latecomer firms.

Therefore, it is sufficient to distinguish only two stages over the evolution of latecomer aerospace industries. An *emergent phase* in which some companies find a niche for their products, and the subsequent phase in which companies aim for *sustained competitiveness*, which is needed to sustain sectoral growth in order to catch-up with the leaders. For example, the maiden flight of a locally designed new aircraft prototype may signal the successful accomplishment of the emergent phase, but it is not sufficient to ensure sustained growth. Further innovation in the long run needs to be financed from sales, which depends on whether a market niche has been found for the new product. Government financing of ‘infant’ firms in the sector is widely accepted. But unless state-sponsored producers generate sufficient sales in markets independent from procurement by the respective governments, they will not be financially sustainable. Eventually, governments and domestic transport firms will be forced to purchase high quality aerospace products from foreign competitors.

It is by no means guaranteed that the second phase follows progressively from the first one, or that competitiveness can be sustained. In successful cases of aerospace development, there is a transition to sustained competitiveness. But this transition can also fail in which case the industry will languish or disappear altogether.

DOI: 10.14267/phd.2016013

3.4 Systems of innovation

The literature on technological capabilities offered a richer understanding of the learning mechanisms or technology accumulation. Authors argued that the simplified description of development processes as passive transfers of embodied and disembodied technologies from leading countries is misleading. The cornerstone of latecomer catch-up was active learning, which is realized through interactions. Successful latecomers were not simply imitators but organized production and distribution in innovative ways, often using advanced science and technology to move into nascent industries (Freeman and Soete 1997; Fagerberg and Godinho 2005). Some authors stressed that one should not distinguish between the processes of innovation and diffusion, since *"diffusion involves more than the acquisition of machinery or product designs and related know-how. It also involves continuing, often incremental, technical change to fit specific situations and to attain higher performance standards"* (Bell and Pavitt 1993, p.259). If that is the case, understanding the functioning of innovation systems brings us closer to understanding latecomer dynamics.

3.4.1 On the origins of the concept

An innovation system is generally defined as a set of actors from whose interactions new knowledge, technology and products are generated, diffused and applied. The 'systems of innovation approach' received increased interest of scholars and policy makers in recent decades for two main reasons: in order to better understand (1) the differences in *growth* performance of countries, and (2) the processes of *technological change* and *innovation* at various levels. Concerning the first aim, the results of evolutionary economics, new growth theory and the economics of knowledge provided very clear evidence on the importance of innovation and technological factors to growth. Furthermore they highlighted the crucial role of interaction among firms and other organizations for innovation, which are conditioned by institutional environment. To offer an alternative to "reductionist" models, the IS approach emerged to offer a broad framework of analysis for technological, economic and institutional change.

Seen from a different angle, scholarly interest in technology and growth shifted away from specific sectors to a broader focus on national institutions and networks in which all elements play their parts in growth. This happened at a time when Western Europe and North America experienced a slowdown in growth and saw the rapid rise of Japan. A seminal study was the analysis of Japan by Freeman (1987). Complemented

DOI: 10.14267/phd.2016013

with the volumes by Lundvall (1992) and Nelson (1993), these are the 'Triad' of basic references on innovation systems (Edquist 1997; Lundvall 2007; or Soete *et al.* 2010). The innovation systems approach was primarily influenced by the results from evolutionary economics and science and technology studies. Results include the ideas that innovating actors face uncertainty and bounded rationality, that innovation requires interactions, that institutions and history matter, or the dynamics of techno-economic paradigms. Already from the very beginning, innovation systems have been a very inclusive (or 'holistic') concept. It has attempted to map 'the big picture' by looking at as large a set of determinants of innovation as possible. In response to studies that only treated limited data on R&D inputs and personnel or patents, the growing literature has accommodated various narrower and broader definitions of innovation. This 'catch-all' nature of the concept has not diminished over time, despite some authors' attempt to introduce greater methodological rigor (see the 'comparability' critique below).

At the macro level, List's systemic view of a developing economy is clearly reflected in the innovation systems concept. With regard to the micro level, the systemic view of the innovation process can be traced to the synthesis of debates in innovation studies (such as the 'technology push' vs. 'market pull') or the idea behind the 'chain linked' models of innovation (Kline and Rosenberg 1986). Moreover, due to their interaction, the macro and micro levels co-evolve. Seen from a firm's point of view, innovation depends on technological opportunities, the availability of loans and (venture) capital, a legal regime guaranteeing the appropriation of results, many of which lies beyond their control. On the other hand, if governments strive to become competitive and achieve growth in their countries, they need to provide a favorable institutional environment for firms to innovate.

The recognition of these interdependencies resulted in an increased scholarly interest in comprehensive, descriptive studies of the processes of social, economic and technological change in a historical and institutional context, or appreciative theorizing, combining elements of political economy, evolutionary economics, history of technology and social constructivism. At the 'meso level' the analysis of industrial dynamics found support in empirical and modeling works on interactions between consumers and producers or knowledge actors (Malerba 2007).

Following from the understanding that interactions are at the heart of the innovative processes, *institutions*, the rules and norms that govern them are central to the IS approach. There is a clear agreement that institutions cover market as well as non-

DOI: 10.14267/phd.2016013

market interactions and provide the 'fiber' of innovation, unfortunately there is no single definition of institutions. Some authors refer to educational or research institutes as institutions (i.e. Nelson 1993) while others call them organizations. Institutions in this book are defined according to North (1990) as "rules of the game", and are distinguished from organizations which are considered as actors of the system.

3.4.2 Level of analysis

The National innovation systems perspective, which associated differences in growth across countries with institutional differences affecting creation and diffusion of new technologies, assumed that national borders mattered. Based on Landes (1969), Nelson and Rosenberg (1993) argued that historical and cultural differences, the timing of industrialization process and government policies shaped national institutions, laws and policies. This gave rise to a debate from two directions. First, it was questioned whether innovation activities and their effects were bound by national borders. Ideas and research results are easily exchanged in a global community of researchers and are difficult to appropriate, firms technological collaboration are often international, and regional integration often also covers science and technology (see i.e. Freeman and Soete (2009) or Caracostas and Soete (1997) on 'post-national systems of innovation'). Shifting the geographical focus to sub-national level of clusters and regions revealed differences in innovative activities due to institutional differences in the 'regional innovation systems' literature (Cooke 1996, 2008; Maskell and Malmberg 1999; Malmberg and Maskell 2002; Asheim and Gertler 2005; Doloreux and Parto 2005).

Second, it was debated whether differences between innovation systems were technology-specific or sector-specific. This was primarily a methodological "point of entry" problem about whether the dynamics of a technology domain or the dynamics of an industry are of interest. Two different strands of literature emerged. The 'technology-specific innovation system' strand is concerned with the systemic explanations of technological change as well as their societal implications (Carlsson and Stankiewicz 1995; Jacobsson and Johnson 2000). The 'sectoral innovation systems' literature (Breschi and Malerba 1997; Malerba 2002, 2004) focuses on questions of innovation, competitiveness and industrial performance in a sector which is defined by a set of products.

Malerba (2004) argued that differences in the sectoral environment explain differences in the processes of learning and innovations. *Sectoral systems of innovation*

DOI: 10.14267/phd.2016013

(SSI) are defined by three major 'building blocks': (1) actors, (2) the knowledge base and the technological domain and (3) their systematic interactions and institutions. Actors encompass not only firms, but also non-firm organizations as well as individuals. They range from producers to users, input suppliers, universities and research organizations, financial institutes, trade unions, technology associations, entrepreneurs and scientists. The importance in the innovation process of different types of actors differs from sector to sector. Actors in a sector are heterogeneous, and their different technological and learning capabilities, beliefs, objectives and organizational structures are all sources of sectoral dynamics. Their behavior and interactions take place in an environment that is shaped by different institutions: norms, routines, common habits, established practices, rules, laws, standards, etc (see North 1990). Some rules are more binding than others; some are more formal than others.

3.4.3 Applying the sectoral systems of innovation approach for latecomer aerospace industries

The sectoral systems of innovation approach can add useful insights to a study on sectoral growth and catch-up in latecomer aerospace industries. First, it offers a "mapmaking" tool for an exploratory study. In an industry where history plays an important role in explaining industrial dynamics, it duly focuses on the heterogeneity of actors, their changing capabilities, the quality and frequency of their interactions. A detailed, qualitative study is crucial to understand why the industry is performing well in one country and what structural failures or institutional blockages hamper innovation and growth in others. It can also reveal what actual tradeoffs innovating firms or policy makers face.

Second, the sectoral innovation systems approach is suitable because it focuses on the "meso-level". If innovations in complex products were the object of our research, the recent work of Hobday *et al* (2005) and Dosi *et al* (2003) could be an alternative point of entry.[24] But innovation and growth in a sector are of course influenced by firm-level dynamics, and similarly by macro-level national policies. Our approach thus needs to be more comprehensive, beyond the micro level but below the national level, and can be called as a national-sectoral approach.

[24] The 'complex product systems' (CoPS) literature on system integration which takes place within as well as between firms. It also explains industrial dynamics since modularity in complex products is reflected in industrial structures and alliance formation. The aerospace industry is often showcased as an example for such a system.

DOI: 10.14267/phd.2016013

Innovation systems approaches have often been criticized for the lack of a clear definition on what belongs to the system and what remains outside its borders. Lundvall's suggestion to overcome this problem was to identify the core and the wider setting of an innovation system (Lundvall 2007). The newly emerged 'functional strand' of innovation systems literature suggested focusing on key functions which systems fulfill (Liu and White 2001; Carlsson *et al.* 2002; Hekkert *et al.* 2007; Bergek *et al.* 2008). Seen from a different angle, a set of products can also define sectoral system boundaries (Malerba 2004), although radical innovations in the long-run will most likely modify them. Nevertheless, a product-core can also be applicable in the long-run in case of a catching-up industry, where this core is 'extrernally-given' by those at the technology frontier.[25]

Another point of criticism of innovation systems studies is their lack of comparability over time and space. This can be an important methodological problem, since the framework only defines the building blocks of systems in general, but there is large variation within the categories. Those studies that take a comparative perspective employ indicators on building blocks and innovation in a systematic way and offer valuable insights (at the national level e.g. Nelson (1993), or at the sectoral level (Mani 2005, 2009; Intarakumnerd and Fujita 2009). This is definitely a direction worth pursuing. Nevertheless, one should exercise caution when trying to measure the performance of an innovation system in transition, for Szalavetz (1998) pointed out that "hard indicators" can be misleading.

3.4.4 Incremental and radical changes in innovation systems

From the very origins of the concept, innovation systems have conceptually been associated with socio-economic change. With the increasing availability of longitudinal data on innovative performance of interrelated actors, there is increased interest in understanding how systems change over time, both in qualitative and quantitative terms (Lundvall *et al.* 2006; Dodgson *et al.* 2008). Fundamental changes in the economy as a result of creative destruction (Schumpeter 1934) or the emergence of new technological paradigms (Dosi 1982; Freeman and Perez 1988; von Tunzelmann *et al.* 2008) have been widely discussed. These theoretical works focus on an aggregate level. We still need to expand our understanding of the co-evolution of science and technology,

[25] The fact that technology applied for aerospace production may originate from other sectors does not reduce the power of the approach, as long as the technology flows are carefully considered.

DOI: 10.14267/phd.2016013

innovation and production and the relevant institutional arrangements at sectoral levels. In other words, how are changes in the innovation system connected to changes in a sector's physical production?

Evolutionary aspects of innovation systems have received increased attention in recent years.[26] Two distinct patterns of system change are crystallizing from these works. The first type of change refers to *incremental changes* along a given trajectory (bounded by path dependence). The study of the Taiwanese integrated circuit industry by Lee and von Tunzelmann (2005) provides useful insights into this type of dynamics, in which the interplay of sub-systems and major actors are at the core of a more gradual system change.

The second type of innovation system change refers to a more fundamental system *transition*. In the 'appreciative theorizing' model of Galli and Teubal (1997) paradigmatic changes and structural adjustments of national innovation systems are driven by exogenous environmental pressures. The changes involve restructuring of networks, changing openness to the outside world, increased interactions between the subsystems (i.e. inter-firm relations evolve beyond simple market-based transactions), and the creation of new technology interface units. Lundvall *et al* (2006) singled out institutional rigidity as the key barrier to growth of a NIS beyond a certain point. System transitions refer to changes in the "constellation of institutions" and changes "in the relationship between producers and users of knowledge". A system transition is required to overcome a contingency mismatch (when change in the environment makes the existing institutional set-up ill-suited for new conditions) or when a system reaches its inherent limits as a result of endogenous growth. In the domain of technological systems, in the multi-level framework proposed by Geels and Kemp (2006), transitions are shifts between technological trajectories, which involve the emergence of a radical innovation incubated in a 'technological niche'. Transitions are also discussed in the functional dynamics literature, where the authors associate the fulfillment and interaction of functions as a prerequisite for systemic change (Hekkert *et al.* 2007; Bergek *et al.* 2008). Considering that functions are inherent in all institutions, it is fair to say regardless of the perspective, all strands of literature appear to agree that

[26] (C.f. Galli and Teubal 1997; Lee and von Tunzelmann 2005; Lundvall *et al.* 2006; McKelvey and Holmén 2006; Geels and Kemp 2007; Edquist and Hommen 2008; Dodgson *et al.* 2008; Dolata 2009; Malerba and Mani 2009),

DOI: 10.14267/phd.2016013

following a successful transition, the basic functions or structure (or architecture[27]) of a new system will look fundamentally different from the previous one.

The cyclical nature of the aerospace industry requires a model that incorporates not only incremental but also radical innovation system change to explain latecomer development. Recurrent booms and slumps in demand regularly pose challenges to both production and innovation. It is reasonable to assume that not only firms, but the system as a whole is affected by demand fluctuations. The industry's performance depends on how the innovation system as a whole manages to cope with these fluctuations.

A central problem with *quantitative* analysis of radical and incremental innovation system changes is often the lack of detailed long-term data. Nevertheless, change in inputs, demand and output; changes in the number of actors or changes in the intensity of interactions (network characteristics) are indicative of the dynamics on innovation system. But in addition to looking at such indicators, *qualitative* analysis is required to highlight changes in the knowledge base and learning processes, changes in the nature of interactions among actors (including change network hub change), institutional change, changing processes of variety generation and selection.

3.4.5 The punctuated equilibrium model of innovation dynamics

The punctuated equilibrium theory on innovations assumes that there are two kinds of changes defining long-run technological development. The more subtle incremental innovation is from time to time punctuated by discontinuities and radical change. The theory originates from evolutionary biology and gained popularity in the innovation and especially in the management literature after the 1970s.

Abernathy and Utterback (1978) linked the two types of technological changes to the maturity of enterprises. Early on, new firms enter the market with radical product innovations. If these innovations become dominant designs, their producers shift focus from product to process innovations. Tushman and Anderson (1986) demonstrated at the industry level in three cases (minicomputer, cement and airlines) that technological innovation follows a punctuated pattern. They also showed that major technological breakthroughs in a sector do not necessarily result in high environmental turbulence, as long as these are initiated by incumbent firms. However, if new entrants introduce

[27] The management literature offers interesting insights as well. The concept of *architectural innovation*, introduced by Henderson and Clark (1990) originally refers to changes on the product level in the way the main components are linked together. Consider the product design architecture as a simple system, a structural change of the linkages of the system that offers a competitive edge to a firm is analogous to architectural innovation in a national or sectoral innovation system.

DOI: 10.14267/phd.2016013

radically new technology, it will be competence destroying for existing firms and will increase competitive uncertainty. Romanelli and Tushman (1994) showed that a similar pattern of changes characterizes organizational development. Equilibrium periods, which are relatively long periods of stability, are punctuated by “relatively short bursts of fundamental change”. These radical changes create new activity patterns for the organization and settle into a new equilibrium. Their reasoning why stability periods emerge can be relevant for the industry level as well, not only at the organizational level. They argued that actors (buyers, suppliers, financiers) are legally and normatively linked to one another and these relationships constrain their activities. In short, institutional inertia is an important source of stability. A further explanation of institutional stability is found in technological community dynamics. Rosenkopf and Tushman (1998) show that cooperative technological organizations emerge in times of radical change (in periods of ‘ferment’) and become dominant communities for over a longer period while technology changes incrementally.

Combining these results has important consequences for long-run sectoral innovation systems dynamics. According to the theory, two of the key components of sectoral innovation systems, the technology base and the actors evolve along a trajectory characterized by incremental changes punctuated or interrupted by radical changes. Malerba and Orsenigo (1996a, 1996b) confirmed that the interacting technological, organizational and institutional changes as well as changing demand define the internal dynamics of industries. It follows that radical changes should also characterize the evolution of sectoral innovation systems. There are two questions. First, is it possible to identify these changes? Second, do such radical changes occur in technology followers or only at the technological frontier, to which the previous studies referred to?

3.5 Previous studies on innovation and growth in latecomer aerospace industries

Scholars of innovation, economics of technological change, industrial organization, political science and sociology have all found ample room for research in the aerospace industry. The factors that influence the creation of a new aerospace product are just as much technological as economical or political. The multifaceted nature of the industry offers various points of entries for research which we briefly present in this section. Approaches concerned here are those focusing on innovation, technological change and

DOI: 10.14267/phd.2016013

industrial growth in the long run.[28] First we look at studies on countries at the technological frontier, next at studies of latecomers.

3.5.1 On the evolution of the aerospace industry at the frontier

For much of the second half of the 20th century, developments in the US were equivalent to developments at the technological frontier. Mowery and Rosenberg (1985) studied innovation and institutional development in the commercial aircraft industry in the US. They showed a long-run transformation in the innovative performance and industry behavior due to changing policy regimes. A shift from public to private funding and deregulation at the end of the 1970s increased development costs and financial risks for aircraft and engine producers, who in turn found a solution in multinational collaboration. Subsequently international collaborative ventures have increased competitive pressure on components and parts manufacturers. Mowery (1987) and Esposito (2004) take a closer look at alliance formation in the sector.

The effect of the aerospace industry on economic growth has puzzled many economists. Surprisingly, no one ventured to measure its contribution to GDP growth in the same way Fogel (1964) has analyzed the contribution of railroads.[29] But there are a number of other attempts that led to interesting results. In a historical approach Ruttan (2006) argued that in the US general purpose technologies developed due to defense purposes (such as satellites or the internet) spurred economic growth. Poole and Bernard (1992) found a negative impact of military production on total factor productivity growth in aircraft manufacturing in Canada. Eliasson (2010) calculated positive spillover effects of a Swedish fighter jet development program.

The growth effects of the industry are most clearly visible at the regional level. There is a growing literature on aerospace clusters, ranging from Seattle (Erickson 1974) and Montreal (Niosi and Zhegu 2005, 2010) to Southern UK and Wales (Beaudry 2001; Cooke and Ehret 2008, 2009).

The aircraft industry has long inspired scholars of technological change and evolutionary economists (see e.g. technological paradigm shifts in (Dosi 1982). In a series of articles Vincenti discussed the evolutionary nature of development in technologies such as air propellers (1979), flush riveting (Vincenti 1984), airfoil design

[28] This also implies that important issues such as market dynamics and firm behavior, competition and collaboration (Golich 1992; Hayward 1994) or strategic trade theory (Brander 1981; Brander and Spencer 1985; Lawrence 2001) are left outside the scope of this investigation.

[29] Such a calculation is not without challenges. Time saving due to air travel in contrast with rail or intercontinental sea travel could reveal some of the effects.

DOI: 10.14267/phd.2016013

(1986) and retractable landing gear (1994). Frenken *et al.* (1999) tracked variety and niche creation, Frenken and Leydesdorff (2000) studied scaling trajectories. Benkard (2000) showed that technological accumulation is not simply a process of constant learning, but as firms evolve they make strategic choices on both learning and forgetting certain production technology.

Aerospace firms in countries such as Canada or Japan are also relative latecomers compared to the US and provide interesting insights into understanding technological learning and capabilities accumulation (see Lukasiewicz (1986) on the failed fighter jet development in Canada; Mowery and Rosenberg (1985), Kimura (2006, 2007), McGuire (2007), King and Nowack (2003) on the accumulation of technological capabilities in Japan).

3.5.2 On the aerospace industry in latecomer economies

The historical experience of Latin American and Asian countries with the aerospace industry since the 1960s and 1970s has been increasingly studied to answer questions such as why countries chose to enter the sector; how they managed technology accumulation in aerospace and in related industries; how clusters were formed; what government policies and firm strategies were followed.

The early realization of the importance of institution building in the development of the sector allowed for a political economy perspective, especially if these studies focused on government policies. In addition, insights from the management literature were used to explain firm strategies. The export success of Brazil made it one of the benchmark cases (Sarathy 1985; Moxon 1987; Ramamurti 1987; Frischtak 1992, 1994; Goldstein 2002a, 2002b; Goldstein and McGuire 2004). Other countries and companies studied included Indonesia (McKendrick 1992; Eriksson 2003), China (Nolan and Zhang 2002; Goldstein 2006), and Argentina (Hira and Oliveira 2007). Texier (2000) provides insights on South Korea by explaining a conglomerate's diversification into aerospace.

Product and industry life cycle theories (Vernon 1966; Abernathy and Utterback 1978; Utterback and Abernathy 1975; Gort and Klepper 1982) offered a generic explanation as to how and why aerospace products diffuse to developing countries during the more mature phase of their life cycle. Niosi and Zhegu (2008) show that these theories are only partially appropriate to explain developments in the industry. They are valid to the extent that developing countries only entered the industry after a

DOI: 10.14267/phd.2016013

shakeout occurred during and after the Second World War. However, there was no clear evidence of a shift of production and innovation to new competitors in developing countries as new competitors mostly emerged in industrialized countries. Moreover, there were several cycles during the 100-year development of the industry, and at least two dominant designs emerged. They conclude that product and industry life cycle approaches should be complemented with a look at sectoral innovation systems. The studies by Marques (2004), Marques and Oliveira (2009) and Mani (2013) are good examples of how the sectoral innovation system facilitated technological capabilities accumulation in Brazil and India. Baskaran (2001) and Steenhuis *et al.* (2007) emphasized the importance of both indigenous efforts as well as interactions between domestic and foreign actors, because a strategy of self-reliance is bound to fail. Romero (2010) discussed the recent trend of foreign aerospace firms moving to a developing country (Mexico), and shows the attracting force of clusters.

All these studies have expanded our understanding of the aerospace industry in emerging economies. They provide for the insights and short-term data needed for analyzing long-run catch-up patterns. But the possibilities for further research remain ample. First, firm or country-level case studies on company growth or innovative performance are most meaningful in an international comparison. This has not been possible due to lack of comparative data, as many of the studies explicitly point out. Ideally, a comparison should be comprehensive and take into account industry leaders as well as other latecomers. It should – ideally – also cover measures of industrial and innovative performance. A second possible direction for research is to explore and explain industrial dynamics of the sector across countries, over a long time-span. The aim would be to shed light on the co-evolutionary processes in national-sectoral innovation systems. It also opens a window on understanding how emerging companies succeed over time on the local and global market.

3.6 Technological change and industrial dynamics in the global aircraft industry of the jet age

The technological frontier in aircraft manufacturing was shifted outwards again and again by innovators located in the advanced industrialized economies, creating a moving target for latecomers to catch up with. In order to see what the benchmark for latecomer innovators was in a given period we provide here a general overview of major changes in key technological domains, including changes in the organization of

DOI: 10.14267/phd.2016013

production. A detailed study of technological development in the global aerospace industry is beyond the scope of this book. Rather, we will discuss major technological leaps in a stylized manner. Next we turn to major milestones in the global aircraft industry (mainly in the commercial industry), which happened in what many (i.e. Frenken 2006) called the paradigmatic phase of the jet era. The diffusion of the jet engine, increased intercontinental air traffic, and major changes in financing aerospace innovation has led to innovation in the organization of the industry. Understanding the main drivers of internationalization for leading producers is important to understand the context in which latecomers can operate.

3.6.1 Major driving force of innovation

Innovation in aircraft manufacturing took place in four domains: propulsion, applied materials, avionics, and the organization of the design and production process.

The importance of demand in driving innovation can be seen in the first row of Table 3.1 which summarizes the generic considerations driving technological advance in aircraft and engine development. Of course, demand is specified in light of what is technologically feasible, but at the aggregate level of the industry, there are a few rather distinct goals.

It is interesting to see on the one hand that from the 1970s further speed increase lost its importance, which happened at the time when jet technology became mature with the diffusion of the turbofan engine. On the other hand, the oil crisis and subsequent decrease in military spending directed attention to energy efficiency and cost reduction.

Propulsion in aircraft manufacturing has undergone a radical change from propeller to jet technology (discussed in section 3.6.2). Since the 1950s itdeveloped along a single trajectory and innovation was primarily incremental (see discussion above in turbojet and turbofan technology).[30] The maturity of the engine industry is reflected in the small number of turbofan, turboprop and turboshaft (for helicopters) engine producers.[31] Propulsion of rockets, missiles and spacecraft has seen more radical innovation,

[30] There were of course other more significant technological innovations, such as the application of results from turbojet technology to propeller systems, by creating turboprop engines instead of piston engines.

[31] As discussed above, the three major manufacturers are General Electric Aircraft Engines and Pratt & Whitney (United Technologies) in the United States and Rolls-Royce in the UK. In addition to these companies (and their joint ventures) who are controlling the large civil aircraft market, smaller engines producers (for commuters, executive jets or military aircraft) include SNECMA and Turboméca of France; MTU (DaimlerChrysler) of Germany; Volvo Flygmotor of Sweden; FiatAvio of Italy; Aero Engine Corporation in Japan; Williams International, Textron Lycoming, Honeywell of the US, and Klimov, Kuznetsov, Aviadvigatel, and Saturn of Russia.

DOI: 10.14267/phd.2016013

although liquid fuel systems still represent the dominant design, despite their disadvantages (cannot be turned off after ignition, relatively low thrust per quantity of fuel consumed).

The choice of *materials* not only defines strength and durability, [32] but it is also central to efficiency in aerospace. One way to boost efficiency is to create more powerful engines using metal alloys[33] that can withstand very high temperatures (over 1000°C). Another way is to reduce structural weight by using composites. Composites are materials combining two or more (in)organic components. They offer the advantage of light weight, yet still strong structure and thus help reduce operating costs. Fiberglass was already applied in the automobile industry in the 1950s. During the 1960s and 70s, new materials such as boron/epoxy, graphite/epoxy; kevlar/epoxy were diffusing to secondary aircraft structures, originating mostly from military programs. Despite the promising weight reduction they offer, composites have serious drawbacks that explain why so many producers have chosen not to use them in primary structures. In comparison with metal components, inspection of flaws in composites is more difficult and production is more costly because of its labor-intensity. Maintenance costs are also higher because, unlike with metal, repair of composites is not possible, and replacement parts are once again more expensive. Boeing aircraft produced in the 1970s and 80s were using composites accounting for hardly more than 3% of total weight, and the first Airbus model contained around 5% composites. The A-320 of the mid 1980s was the first commercial aircraft to have 10% composite share, the first Boeing with a similar share was the B-777 (Table 3.1). Military aircraft, mostly because of different MRO requirements and stealth considerations, were more ready to use composites, the F-18 E/F and the F-22 of the 1990s had 19 and 24% share respectively.[34] Boeing took a large step with the launch of the B-787 *Dreamliner* which has a fuselage made of carbon fiber, and a composite share of over 50%.[35]

---

[32] Strength and durability requirements have led to the increased use of steel and titanium. Titanium and its alloys have a high strength/density ration, are corrosion resistant, high operating temperature and are compatible with composites, yet they are difficult to form and have high machining costs and high notch sensitivity. (For more on materials used in aerospace, see Mortensen (2007).)

[33] Metal alloys are substances composed of two or more metals or of a metal and a nonmetal; mostly created by melting and dissolving the components.

[34] Deo, Ravi B. *et al* “Low-Cost Composite Materials and Structures for Aircraft Applications” http://ftp.rta.nato.int/public/PubFullText/RTO/MP/RTO-MP-069%28II%29/MP-069%28II%29-%28SM1%29-01.pdf

[35] The composite structure has been a source of significant delays in the launch of the B-787. Boeing dismissed the criticism concerning maintenance difficulties, but the plane is currently undergoing testing and is yet to see daily commercial operations.

DOI: 10.14267/phd.2016013

Table 3.1 Overview of major new-to-the-world innovations in civilian aircraft

	1950s	1960s	1970s-80s	1990s	2000s
Major goals for innovators[a]	Speed increase	speed and capacity increase	Economical use, fuel efficiency increase	Cost reduction, noise reduction, capacity increase	environmental considerations (Lower CO_2 emissions), increase airline revenue, cost reduction
Major innovations in aircraft propulsion[a]	Turbojet: P&W JT3C (1952); Turbofan: P&W JT3D (1958)	Turbofan: P&W JT8D (1964), JT9D (1966); RR RB211 (1969) GE CF6 (1971);	Turbofan: CFM56 (1974); P&W PW2000 (1979), PW4000 (1987); RR RB211-535 (1983); IAE V2500 (1983)	Turbofan: RR Trent 700 (1990); -800 (1993); P&W PW4000-100 (1994), GE90 (1995)	Turbofan: RR Trent 900 (2004)
Most advanced aircraft types	*Comet I*; *Caravelle*; Tu-104	B-707, DC-8; B-727; B-737; *Concorde*	B-747; DC-9; B-737; A-300; L-1010; DC-10; B-757; B-767	MD-11; B-777; A-330; A-340	A-380 B-787
Applied materials; (Composite share of weight)	Aluminum; steel; metal alloys	Aluminum; steel; metal alloys, composites (fiberglass; boron/epoxy)	Aluminum, steel; titanium, metal alloys, Composites (boron/epoxy; graphite/epoxy; Kevlar/epoxy): B-737: ~3% ; B-747: 2%; B-757, B-767: 3%; A-300: 5%; A-310: 7%; A-320: 15%;	Aluminum, steel; titanium, metal alloys, Composites: B-777: 10% composite; A-330/340: 12%	Aluminum, steel; titanium; metal alloys, Composites: A-380: 20% B-787: 50+%
Internationalization of production[b,c]		Share of foreign components: B-707: 0% B-727: 2%	Share of foreign components: B-737: 10% (1970s) B-767: 15% (1980s)	Share of foreign components: B-777: 30%	Share of foreign components: B-787: 70% (60% of all products)
Avionics	None (Independent, analogue instruments)	First appearance of on-board electronics	Fly-by-wire; (first-all-digital: A320 1984) CRT electronic flight displays; inertial navigation systems, auto-landing systems	LCD display; satellite communication, GPS navigation; integrated modular avionics	Electronic flight bags; air-ground data link; terrain awareness system;

Source: Own compilation based on (a) Sehra and Whitlow (2004, Fig.1); (b) Craypo and Wilkinson (2003, p.294); (c) “Globalization Bites Boeing” *Businessweek* 13 Mar 2008; Mortensen (2007);

DOI: 10.14267/phd.2016013

Technological advance in *avionics* has accelerated in the past decades. A substantial share of the information and communication technologies and electronics used in our daily life include parts or solutions that were developed in aerospace applications. Before the 1960s onboard sensors, displays and controls were analogue and independent from one another. The mechanical instruments were gradually replaced by computers with increased interconnectedness. Avionics are used for a broad range of functions, including navigation and communication, flight control, engine control, flight management, subsystem monitoring and control, collision avoidance and weather detection. Additional functions in military aircraft include radar, infrared and other target sensors, weapon management, electronic countermeasures, mission planning, or formation flight control. By architecture, they encompass displays, controls, computation, data buses, safety partitioning, environment, standards (Kayton and Fried 1996).

Flight data processing and instrument panel displays have changed radically in recent decades. During the 1960s and 1970s, R&D focused on onboard computers ad cathode-ray tube (CRT) technology. By the 1980s the first ‘glass cockpit’ aircraft were introduced (B-757/767, A-320). Flight management computers and displays giving feedback on engine and subsystem performance significantly reduced cockpit workload and made a separate flight engineer unnecessary in the cockpit.[36] CRT displays were heavy and bulky, and were replaced by LCD screens in the 1990s. They became also very popular in general aviation, where single-pilot operations were fundamental.

Commercial aircraft today contain over a thousand sensors and boxes of electrical components. The very high reliability, safety and testing requirements (both in hardware and software) and complex architecture make avionics very costly aircraft components, typically amounting to 30 percent of aircraft costs. (In advanced military aircraft they can even reach even exceed 50 percent, in some spacecraft 70 percent.)[37] Today the market is dominated by Rockwell Collins or Honeywell of the United States, Thales Avionics in France, and BAe Systems of the UK. A burgeoning set of international suppliers and partners provide sub-systems.

---

[36] Most airliners in the 1950s flew with a crew of 3 or 4. New displays reduced pilot eye scanning cycle by providing primary data on a single screen. The basic concept of Boeing’s Engine Indication and Crew Alert System developed the B-757/767s can be found in the latest models.

[37] The increased complexity of avionics software development can be seen in two indicators: cost of software development for U.S. defense programs rose from $5 to $35 billion between 1985 and 1995; Military aircraft of the 1960s had 20,000 lines of codes, modern fighters and commercial transports have several million. (“**Aerospace industry**” *Encyclopaedia Britannica Online*. Retrieved: 22 Oct 2010)

DOI: 10.14267/phd.2016013

3.6.2 The diffusion of the jet engine

The rapid expansion of the industry is related to the radical changes brought about by the jet engine in military and commercial aviation. The resulting expansion of air transport in turn has shrunk the planet and allowed an unprecedented scale of international collaboration in development, production and marketing in all industries, including aerospace itself.

The jet engine was first patented by Sir Frank Whittle in 1930, but in 1939 Hans von Ohain was the first to design one that actually powered an aircraft, the Heinkel He178.[38] The main advantage of the jet technology[39] over the dominant piston engine of the era was a significantly greater power to weight ratio. Given its strategic potential, the turbojet technology diffused rather fast across countries during World War II. In Germany, Messerschmitt 262 flew for the first time in 1942. In the same year in the United States the GE I-A engine mounted on a Bell P-59 made its maiden flight. In 1943 the British De Havilland *Vampire* fighter flew for the first time and in the following year Rolls Royce started to work on the *Nene* engine. The first Soviet jet fighter, the MiG-9 followed suit in 1946.

Only after the war did the jet technology diffuse in civil aviation. In 1949 the first commercial jet to fly was the British De Havilland *Comet 1*. The aircraft debuted in 1952 in scheduled service between London to Johannesburg,[40] heralding the age of jet transportation. However, the first-mover had to pay a high price because of repeated crashes due, as it was eventually diagnosed, to metal fatigue (see Rosenberg 1976; Verspagen 1999). The reengineered *Comet 3* plane was less successful than the new

[38] Constant (1980) provides a careful study of the evolutionary development of the turbojet engine. The author makes a case for the parallel development both in the UK and Germany.
[39] A jet engine (or gas turbine) operates based on the principle of Newton's third law (for every reaction there is an equal, opposite reaction). Air taken in goes through a compressor and is mixed with fuel in a combustion chamber. Rapidly expanding exhausted gas then rotates the turbine blades and thus provides thrust for forward movement.
[40] In the same year the London-Ceylon and London-Singapore, in the following year the London-Tokyo routes were opened. Flying time between these latter two cities dropped from 85 hours to 36 hours (Loftin 1985).

DOI: 10.14267/phd.2016013

designs developed by the follower competitors[41] from the US, and thus *Comets* lost the market to the Boeing B-707 and the Douglas DC-8.[42]

Almost at the same time, in the Eastern bloc, the Soviet Tupolev Tu-104 flew for the first time in 1955. The *Comet* and the Tu-104 had many similar features, including the wing-root mounted engines, the Tu-104 was a larger, faster and stronger construction. More importantly, the plane had rounded windows and was thus not vulnerable to metal fatigue. Both of these aircraft represented a milestone in aviation history, half-way between the propeller-age and the jet-age. They were pioneers of a new concept, yet in many ways (e.g. wing loading or control systems) reflected the old philosophy of propeller-driven aircraft (Loftin 1985).

Following the introduction of the technology in Europe, a new dominant design emerged in the USA. This was the Boeing B-707, which first flew in 1954 and entered into service in 1958. Boeing's design incorporated the lessons learnt from own military aircraft production (e.g. the B-47) and from European pioneers in commercial aircraft. Low-positioned, sweepback wings offered efficiency at high-altitude, high-speed cruise. Four turbojet engines attached underneath in single nacelles made repair easier. The plane could carry a maximum of 189 passengers to a maximum distance of nearly 12,800 kilometers, allowing non-stop travel over almost all the oceans and continents. The B-707 soon became the most successful jet plane of its age, with over a thousand built by 1979. Frenken and Leydesdorff (2000) showed empirically how the company could exploit the design principles of the B-707 in subsequent rescaled models built to meet user needs (along what the authors called a 'scaling trajectory').

With a very similar design but a longer fuselage, the DC-8 could carry 60 more passengers than the 707 (although at a cost of offering a shorter maximum range: 11,300 km). It first flew in 1958 and entered into service in 1959. In a relatively short production cycle – it was produced until 1972 – a total of 550 were built. These two

[41] The technological leadership of Europe over the US before World War II is undoubted (Moran and Mowery 1991). Nothing reveals better the nature of the competition between the UK and the US than the diplomatic row between the two countries. The Americans may have been trying to win time by tying up British aircraft sales efforts "in security red tape", arguing that the Rolls-Royce *Avon* axial engine powering the Comet 2 as well as military jets constitutes a secret that should be kept out of reach of the Soviets (Engel 2000).

[42] The last of the 114 aircraft produced were delivered in 1964. It is also interesting to see that the nose section and cockpit layout of the *Comet* was used for the French Sud Aviation's *Caravelle* that flew for the first time in 1955 and entered into service in 1959 and became more successful on shorter routes and at airport with shorter runways. The plane could carry 80 passengers (later Super -12 models were increased to 140). A total of 280 were built.

DOI: 10.14267/phd.2016013

planes (and a few very similar followers)[43] brought revolutionary changes to the air transport industry. Trans- and intercontinental travel grew rapidly as it became faster and more accessible to large part of society. In the US high fuel consumption, at least before the oil crisis, was a less important issue. The long take-off runway requirement (3 km) of these jets triggered the development and construction of new airports. As Moran and Mowery (1991) note, the US federal government was always ready to bail out defense contractors (such as Douglas or Lockheed) when they were overrunning costs with commercial aircraft development. Moreover, the world's largest market, the US, was highly regulated, spurring competition not in price, but in service and quality, which in turn boosted the development of new technologies and their rapid adoption. As a result US manufacturers gained a dominant position in the world which they were keen on exploiting for exports as well.

Improvements in engine technology, the development of the more efficient turbofan engine[44], allowed the construction of a second generation of jetliners in the 1960s. New metal alloys made airframes stronger; the introduction of composites (fiberglass and boron/epoxy) made airframes lighter. The introduction of supercritical wing design allowed better performance at higher speeds and lower wing weight. Manufacturers could offer a wider selection of jets to meet various airline preferences based on route length, payload, speed, or runway requirement. Three US designs of this era, the B-727 (first flight in 1963) the DC-9 (first flight in 1965) and the B-737 (first flight in 1967) have become extremely successful and widely used planes around the world.[45] But technological knowledge was not restricted to the US. Other major aircraft sharing the basic knowledge were produced in the UK (the British Aircraft Corporation VC-10 and BAC-111, or the Hawker Siddeley HS.121 *Trident*), in the Netherlands (Fokker F-28), and very successfully in the Soviet Union (The Tupolev Tu-134 and Tu-154 models or Yakovlev Yak-40). Most of these aircraft (except for the B-737) have two or three aft-mounted[46] engines (Loftin 1985).

[43] The Convair 880 (first flew in 1959) and the 990 (1961) were from the same school; the development concept opted for a faster design at the cost of payload capacity and range. These considerations eventually did not make it as popular as the B-707 and DC-8.
[44] By adding another fan in front of, and creating bypassing air around the turbojet core engine, significant additional thrust (and lower noise) can be achieved with only a small increase in fuel flow.
[45] More than 1800 of the B-727 were built by 1984, almost 1000 of the DC-9s and more than 6000 (and still produced) of the B-737s, in a number of gradually improvements in structure and onboard systems.
[46] Advantages of the aft arrangement of engines, according to Loftin (1985) include increased stability in case of engine failure, lower noise levels, and also allow smaller sized planes; however the advantages of a T-tail design are debatable.

DOI: 10.14267/phd.2016013

Another direction of technology development was increased carrying capacity during the 1970s, resulting in wide-body models[47] such as the Boeing B-747 *Jumbo*, the McDonnell Douglas DC-10 and the Lockheed L-101 *TriStar*. The new designs offered significant increases in payload and seating capacity.[48] Larger engines with high bypass ratio and compressor pressure ratio also provided fuel efficiency increases in the range of 20% compared to previous models, combined with lower noise levels.

Increased fuel efficiency was the driver of aircraft development in the 1980s. High by-pass ratio engines power the two new models of Boeing (B-767 and B-757), and these aircraft represent a clear change of track from the previous "faster, bigger and further" plane making strategy.[49] The major innovations incorporated in these aircraft were in avionics and computers.[50] This direction of innovation is even more visible on the models of the era offered by the newly created European competitor, Airbus, which offered for the first time in commercial aviation a fly-by-wire system on the A-320 that first flew in 1987. But this already marks a new wave of increased technological competition in avionics. Instead of conceptual changes the jet technology saw further advancement in refinement, typical of a mature technology.

In sum, technological changes due to the jet engine made the world smaller; transoceanic and transcontinental flights became faster and more accessible. Rapid growth in the number of people transported followed. One of the best indicators of technological progress is the decrease in direct operating costs of aircraft.[51]

3.6.3 Internationalization

Aircraft design and production before the 1960s was primarily done in-house with little collaboration among manufacturers. In the US the development of generic technology received significant boosts from NASA and Department of Defense research funding, in

---

[47] The wide-body design offers greater cabin diameter, the two aisles allow faster loading, serving and evacuation time, but come at a cost of increased skin friction drag.

[48] These aircraft offered a maximum seating capacity of 550, 386 and 400, respectively.

[49] Compared with the latest model of the B-707-320B, the B-767 has nearly the same empty weight yet it can carry 100 more passengers – on shorter routes. The B-767 is also 40 miles slower than the previous model, but allows shorter landing and take-off field lengths (Loftin 1985).

[50] Automatic flight control systems and computers offer automatic guidance and control of these aircraft from takeoff to landing. More advanced lateral navigation functions as well as vertical flight-path control provide a new way to minimize fuel consumption. Pilots have cathode-ray-tube displays at their disposal instead of traditional electromechanical instruments.

[51] From 7.47 USD/seat in case of the DC-3 it went down to 2.61 with the introduction of the B-707 and further to 1.3 with the B-747 and 1.65 USD/seat with the B-757 (Mowery and Rosenberg 1989, Table 7.1.,p.175).

DOI: 10.14267/phd.2016013

Western Europe national champion companies were nurtured (Moran and Mowery 1991).

The emergence of cross-country collaboration was driven by two main reasons (based on Mowery and Rosenberg 1985; or Mowery 1987). First, as a response to high development costs and the limitations of domestic markets, international alliances were seen as a way to share the costs of commercial aircraft development and benefit from economies of scale in production. Already in the 1960s, European producers were starting to explore possibilities to respond to US competitors by setting up joint ventures. One such venture was the Aérospatiale-BAC *Concorde*[52] project of 1962; another was the British, French and West German and Spanish "Airbus Industrie Economic Interest Group" of 1970. Similar projects in the military segment saw more hurdles on the road as projects became more costly and delivery times increased since sharing of technology remained a sensitive issue for competitive reasons even among members of NATO.

Internationalization of production was also driven by government procurement, both by air forces and by state-owned airlines. Because these orders involved high costs and frontier-technologies, government buyers, especially of countries already having an aerospace industry, could bargain for offset agreements. One solution was the local assembly of aircraft from kits under license. This allowed for access to technologies and improvement of skills, but in a more limited way since it did not cover aircraft development or more detailed engineering work. Offset agreements often made arrangements for manufacturing components locally for aircraft purchased from abroad. As a result of growing specialization, joint production programs started already in the 1970s. One example is the General Dynamics F-16 fighter, which included European companies that were also producing components for planes sold in the US.[53] Collaboration at first in production, later in design, to have market access became the general practice in the industry, already by the end of the 1980s. It paved the way for the R&D alliances in risk sharing partnerships to spread development costs.[54] The advance of information and communication technologies in the 1990s allowed arm's length cooperation in all phases of production and a major global consolidation following the drop in military spending at the end of the Cold War.

[52] The supersonic transport aircraft first flew in 1969 and entered into scheduled service in 1976.
[53] See Moran and Mowery (1991, p.141) for details on the program.
[54] Boeing, for instance, offered full partnership to some subcontractors during the development of the B-777, Japanese partners held a 20 percent share in the airframe structure.

DOI: 10.14267/phd.2016013

Alliances and global consolidation were nowhere as visible as in *engine manufacturing*. Already during the “age of national champions” the huge development costs and economies of scale forced mainframe manufacturers to look beyond national borders for jet engines. Engine production itself is a high value added activity since engines could cost around 15-20 percent the value of a new aircraft. European and American countries were keen on retaining part of the work in local companies. This led to the creation of three major joint ventures. The CFM consortium was formed in 1974 by General Electric (GE) of the US and the French SNECMA with equal ownership. CFM engines power major workhorses such as the Boeing B-737 and Airbus A-320 family. The International Aero Engine (IAE) venture of 1983 brought together the competence of the British Rolls Royce, the American Pratt & Whitney (P&W), the MTU of Germany and the Japanese Aero Engine Corporation consortium to power single-aisle aircraft in the 150 seat category. Its V2500 engine soon won the support of Airbus and McDonnell Douglas. More recently GE and P&W formed a 50-50 joint venture, the Engine Alliance to supply the high-capacity long range aircraft, such as the Airbus A-380 superjumbo. But besides these alliances, each company also has their own engine product lines (in a broad range, from regional or executive jets to wide-body aircraft). This duality has led to delays and frictions among partners, as producers imposed restrictions on independent use of acquired technologies, especially if technology was developed for military programs (Moran and Mowery 1991).

During the 1990s, new possibilities opened up for collaboration between the former West and countries of the former Eastern bloc. However, the promises of drawing upon Russian expertise brought only modest results in joint aircraft development. Russia, with a previous annual production of hundreds of commercial aircraft, only produced a dozen commercial aircraft in a decade after the collapse of communism. Unlike Tupolev or Ilyushin, Sukhoi and MiG in the military segment still held on to their markets. Collaboration with Russia was more successful in space research and launches, where fuel efficiency and economic operation was less of a consideration and where Russia still possessed frontier technological capabilities.

The latest aircraft designs of the 1990s and 2000s included Boeing’s B-777 and Airbus A-330 and 340 long-range, wide-body jets that achieved increased efficiency by using 10-12% composite material in their airframe and cabin structures. Boeing led the strategy of using international partnerships to reduce R&D and production costs. Foreign components made up nearly a third of the value of the B-777, and this share has

DOI: 10.14267/phd.2016013

grown to more than 70% in the B-787 currently in the testing phase. The strategic competition of Boeing and Airbus resulted in Boeing going for a radical new design with the B-787 which, for the first time, incorporates a composite airframe raising the composites rate above 50% of the total structure. Airbus on the other hand saw more potential in the large capacities and aimed at size. Its latest A-380 superjumbo is, from the use of composite materials point of view, not a radical departure from the previous trajectory.

In sum, the aerospace industry has shifted towards an internationalized production structure where key assets of producers are core competencies in component or structure design and manufacturing, or system assembly. This further strengthened the pyramid-like hierarchical structure, in which system assemblers are on top, followed by firms that develop and produce primary structures and systems in the second tier below. Subsystem[55] and components manufacturers supply them from lower tiers. Aerospace companies with expertise in different segments can at the same time participate as system assemblers in one program and as co-developers and producers of components (risk-sharing partners) in another, creating multi-tier competition in an oligopolistic market. It is important to understand how the industrial structure has changed by the 1990s, because latecomer producers trying to penetrate the industry today have substantially different competitive challenges to tackle than in the 1960s or 70s.

[55] *Encyclopedia Britannica* provides a rich sample of what may belong here. *"Aircraft secondary systems are reflected in an extensive industrial infrastructure, with products falling largely into four categories: (1) structural and mechanical, (2) propulsion and power-related, (3) environmental control, and (4) communications and navigation. The first category encompasses aerodynamic controls and actuators (mechanical or fly-by-wire systems), doors, engine nacelles and pylon fairings, control surfaces, and takeoff-and-landing-gear systems (including nosewheel steering, brakes, shock absorbers, and tires). The second category covers propellers, thrust reversers, fuel tanks and fuel-management systems, engine starters, auxiliary power units, air-driven generators, and electrical systems. The third category includes pressurization and air-conditioning equipment, ice-detection and anti-icing systems, electronic flight-instrumentation systems, engine-indication and crew-alerting systems, conventional cockpit instruments, and autopilots and flight directors. The fourth category encompasses communication systems, navigation equipment (including radio, optical, electronic, and inertial-reference systems; instrument-landing systems; receivers for satellite-based global positioning systems; traffic-alert and collision-avoidance systems; and heads-up displays), and cockpit voice and flight data recorders. Commercial aircraft add galleys and toilets, onboard entertainment and announcement systems, emergency slides and rafts, and other equipment for passenger comfort and safety. Special subsystems in military aircraft include ejection seats and separable cabins, multimode radar, armament, stores stations for external weapons, electronic countermeasure systems for confusing enemy defenses, arrester hooks for aircraft carrier landings, braking parachutes, identification friend or foe (IFF) systems, and photographic, infrared imaging, and other sensory devices for intelligence gathering together with onboard intelligence-processing equipment."* ("Aerospace industry" *Encyclopedia Britannica Online*, retrieved: 22 Oct 2010)

DOI: 10.14267/phd.2016013

3.6.4 The diffusion of technologies to emerging economies

The case studies in Chapter 6 will discuss the evolution of technological capabilities in greater details. Here we provide a brief overview focusing on the key technologies we presented above. We use the case of the Brazilian producer Embraer to show how certain technologies diffused gradually to an emerging producer.

Diffusion of the jet engine: The first aircraft Embraer started to produce in 1969, the EMB-110 *Bandeirante,* was powered by turboprop engines produced by Pratt & Whitney Canada. Of course, the capability of producing jet aircraft did not necessarily require the capability to produce jet engines even for companies on the technological frontier. Embraer accumulated the jet technology step by step. It assembled its first jet aircraft in 1971. This was a fighter aircraft, the EMB-326 *Xavante*, a 1957 model of the Italian Aeromacchi which was assembled under license in Brazil. The two companies jointly developed the AMX jet fighter in 1984 using a Rolls Royce *Spey* 807 turbofan engine. The first locally designed jet (with also a Rolls Royce engine) was the ERJ-145 commercial regional jet introduced in 1995. At the same time, the production of commercial jetliners requires pressurized cabins. The first Embraer civilian aircraft with pressurized cabin was the executive turboprop EMB-121 *Xingu* (1976).

Composite materials: Simple composites were already used in the first plane, the EMB-110 *Bandeirante*. 'Wet/hand lay-up' technique was applied on a few non-structural components and on fairings[56]. Structural bonding was introduced with the AMX fighter and composites in integrated structures were first used on the ERJ-145 family. Embraer acquired this latter technology when it was producing outboard flaps for the MD-11 and through the eventually failed project of the CBA-123 in the late 1980s. The latest executive jets of Embraer, the *Phenom* (2007) have totally integrated composite structures made with thermoplastic.[57]

Avionics and glass cockpit: Due to the modular design, the diffusion of avionic suits and on-board computers to Embraer aircraft was relatively fast. The joint Italian-Brazilian AMX fighter already had two computers and state-of-the art displays on board. Embraer was cooperating with Rockwell for the avionics on the Brasilia commuter. Through a partnership with Honeywell, the ERJ-145 regional jets were

---

[56] Fairings on aircraft create smoother surfaces in order to reduce drag.

[57] This paragraph was based on Arakaki, F.K. and Goncalves W.G., 2007, "Embraer Composite Material Application", paper presented at the *16th International Conference on Composite Materials*, 8-13 Jul 2007, Kyoto.
Most recently, in 2010, Embraer began to construct its own facility in Portugal to produce composite structures and components.

DOI: 10.14267/phd.2016013

equipped with the latest “glass-cockpit”. The ERJ-190 jet was one of the first commercial aircraft to use head-up display. The latest *Phenom* executive jets are equipped to enable single-pilot operations, which is an increasingly important requirement in the business jet market. Despite the rather fast diffusion of avionics technology to Brazilian aircraft, the technologies continued to be developed elsewhere in the advanced economies. Of course, the technologies have to be tailor-made and adapted locally, but no Brazilian companies emerged as competitors of global avionics suppliers. But this is related to the nature of the Brazilian aerospace innovation system which we shall discuss in greater details in Chapter 6, along with further historical details on technology diffusion in other countries.

DOI: 10.14267/phd.2016013

Chapter 4: Explaining success and failure of catch-up in aircraft manufacturing

4.1 A Theoretical Framework on Innovation Systems Dynamics

It is fair to assume, based on the literature review presented in the previous chapter and on the empirical study of the evolution of the industry that two phases can be distinguished in the development of a latecomer aerospace industry: an *emergence phase* and a *catch up phase*. Firms in an 'emerging' industry have to overcome several barriers to entry: high capital requirements, lack of technological capabilities, lack of access to technology and market-dislocation. Technological barriers are gradually overcome through access to foreign embodied and disembodied technologies and indigenous efforts to adopt and adapt them. This process can greatly benefit from spillovers from other domestic industries. Initially, in the emergence phase, the disadvantages latecomer firms face outweigh the advantages and sustained growth depends on the ability of public actors to support the emergence of a sectoral innovation system. But can a fully-developed innovation system ensure sustained competitiveness subsequently? Considering that the long-term evolution of innovation systems include both incremental and radical institutional changes, it is fair to assume that during the catch up phase the innovation system periodically needs to be reinvented and restructured. Such radical system changes involve a fundamental restructuring of institutions that define the interactions within an innovation system. This is because technology at the world frontier develops in a discontinuous manner and similarly, discontinuities were found in the long-run evolution of actors, firms, organizations and industries. More specifically in the aerospace industry, market volatility and changing demand conditions create recurrent crises which call for radical response from innovation system actors.

A combination of these forces has the potential to create major discontinuities in the catch-up trajectory of a latecomer aerospace industry and interruptions in the innovative processes. We have observed declines and acceleration of growth in the sector in almost all countries. We are now turning toward the evolution of sectoral innovation systems in

DOI: 10.14267/phd.2016013

late entrants to aerospace manufacturing. [58] We propose a conceptual framework to analyze the evolution of latecomer aerospace industries which builds on the sectoral systems of innovation approach and is sensitive to interruptions and radical system changes.

In the following sections we give an overview of the main components of a theoretical framework which investigates discontinuities in the evolution of innovation systems – it reiterates work that has been presented in Vertesy and Szirmai (2010) and Vertesy (2011).

4.1.1 The main components of the framework of interrupted innovation

Over time, innovation systems – and in particular, we think of a sectoral system of innovation in the aircraft industry) can change in many ways: expanding its actors and networks (we can call it growing in size) and the interactions can become more intensive (grow in performance). The *size of an innovation system* is defined by the input of resources into innovation and technological change (investment in R&D, training and education, human capital stock engaged in the development of new products and processes or organizational change as well as marketing or economically applicable knowledge). Increase in the amount of inputs implies an increase in the size of the innovation system. The *performance of the innovation system* refers to the volume of innovative outputs which can be applied in production (knowledge about new products, new processes, organizational innovations, discovery of new resources, patents, etc.). The maximum amount of innovative outputs a sectoral system of innovation can attain with a given combination of inputs under a given institutional structure defines the *performance frontier* of the system.

Innovation performance is difficult to measure in an unambiguous fashion, partly because there are so many dimensions of innovative performance which are hard to aggregate.[59] Indicators characterizing innovation performance could include the number of new product designs, the share of new products in sales or the number of patents, citations and trademarks. In the absence of direct performance measures, one could also use proxy indicators of innovative performance such as the industrial sales performance (including sales on domestic and export markets) and market shares of final products.

[58] While we refer to 'sectoral systems of innovation', we bear in mind the conclusion from the literature review that in the context of latecomer aerospace industries both national and sectoral characteristics matter.

[59] The literature does not provide a clear definition of the performance of a sectoral innovation system. Nor does it provide simple ways to measure it over a long time period.

This is based on the reasoning that in aerospace increases in market shares can only be realized through increased innovative performance.

When the innovation system is supplied with additional resources, innovation performance will tend to increase. But within the limits of a given innovation system, long-run performance is constrained by diminishing returns – similar to a production function with diminishing returns to scale.[60] The larger the size of the system, the more complex it becomes, and the more costly and difficult it will be to coordinate the use of resources effectively.

We illustrate the relationship between size and performance of a sectoral innovation system and the effect of institutional change with the help of a set of graphs. Rather than exact measurement frameworks, these graphs should be seen as metaphors.

4.1.2 Learning within an innovation system

Error! Reference source not found. shows the evolution of the performance frontier curve p in relation to innovation system size (resources available for innovation) increases. There is no reason to assume that the sectoral innovation system in any country performs at the maximum of its potential capacity. As it has been often shown since Nelson and Winter (1982), “producing” innovation is difficult. It requires tacit and codified knowledge. Agents make choices based on imperfect information. Whether the effort brings successful outcome is uncertain. How close a country performs relative to the innovation performance frontier thus depends on the amount of learning taking place in the system. Learning takes place through interaction of the actors in the system. In a simplified way, a country’s vertical movement from point A to B on the graph corresponds to *increased intensity of interactions* among actors. It shows the system’s success in learning the art of innovation, or utilizing the capacity given the amount of resources invested in the system (horizontal axis).

[60] New growth theory (see Romer 1986, 1990, Lucas 1988) states that there are no diminishing returns to increasing knowledge inputs. We argue that this view needs to be modified. Increasing inputs into a given static system of innovation are subject to diminishing returns. Only if the innovation system succeeds in continuously reinventing itself and changing its nature dynamically will diminishing returns be overcome. This requires a kind of transitions from one innovation system to another.

DOI: 10.14267/phd.2016013

Figure 4.1 Performance in a given innovation system

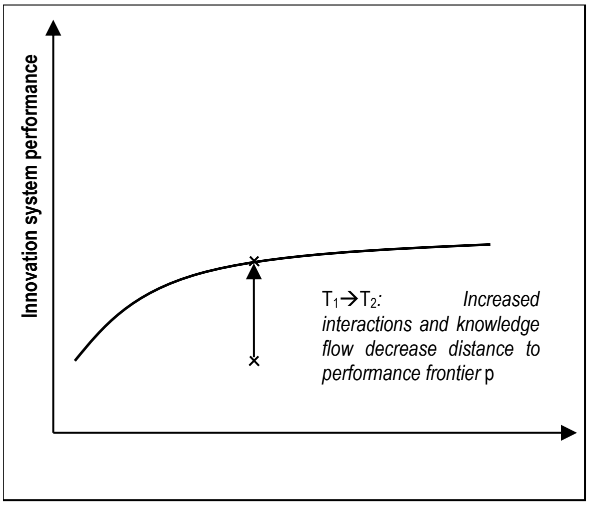
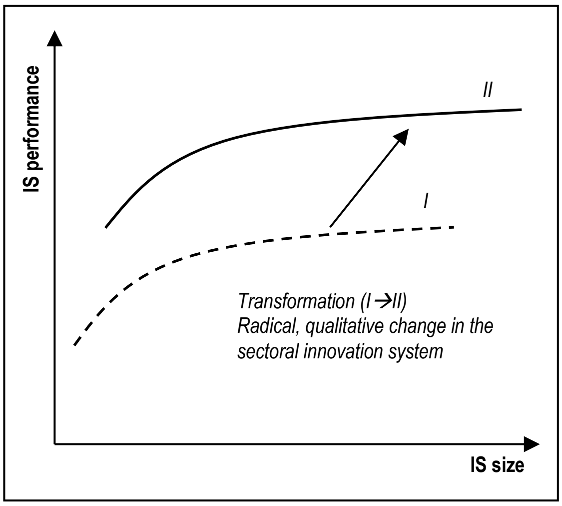


Figure 4.2 Radical Change of the Sectoral Innovation System: Transition



Source: author's compilation

4.1.3 Shift of the innovation system frontier

A shift of the innovation system performance frontier requires radical institutional change. This is different from smaller adjustments in the institutions which facilitate capacity utilization given an innovation system setup. Smaller changes in tax or trade legislation are institutional changes that might affect system performance. Yet they are limited in scope and do not alter the fundamental structure and key channels of interactions of a system.

A radical shift of the system is caused by a more fundamental, qualitative change in its institutional set up. These changes include the entry of new actors with new capabilities that affect existing relations in a fundamental way, a significant change in the technological base of the system, and, crucially, a change of institutional characteristics. Figure 4.2 illustrates this radical change as the *transition* from frontier curve *I* to *II*. Such a shift to a higher performance frontier curve will not only allow an industry to increase its competitiveness, but given diminishing returns to innovation inputs, it is the only source of knowledge-based competitiveness gain beyond a certain size of the innovation system. This is why continued advance in innovation performance requires periodic radical restructuring of the innovation system.

There are a number of empirical issues in innovation system dynamics that this simple model can illustrate. For instance, shifts from defense-oriented to commercial innovation systems, shifts from systems founded on a strategy of import substitution to

DOI: 10.14267/phd.2016013

open systems, or the shift to the hierarchical, risk-sharing-partnership based innovation system structure which characterizes the global industry today.

The aim of any competitive industry is to continue to increase its innovative performance with a given set of resources, in other words, to shift the innovation performance curve upwards. But, the establishment of a new system based on new combinations of resources and new institutions is a very uncertain and risky process, which may well fail. If the institutional memory is destroyed due to external shocks and the inflow of recourses is drastically reduced, the system may not be able to transform itself. The actors in the system may realize that change is necessary, but they also will only be able to realize change if the institutional set up permits them to do so and new resources are forthcoming).

The causes of radical innovation system change in a latecomer industry are most likely exogenous to the system. External macroeconomic, political or technological shocks cause crises and interruptions in the productive activities. If these events are longer lasting, private and public financial resources available as inputs for innovation will be depleted. This depletion can also happen if the innovation system fails to meet the demands of the competitive environment. Technological change outside the system (i.e. in leading countries) can similarly be detrimental to competitiveness of the latecomer system as such changes make the existing knowledge base obsolete.[61] In behind-the-global frontier latecomer systems exogenous causes of interruption are more likely than causes endogenous to the system, which are more typically found in situations where the industry is already operating at the global technological frontier. In advanced economies, innovation at the knowledge frontier may lead to creative destruction, resulting in endogenously driven interruptions.

4.1.4 Innovation system trajectories

Figures 4.3 and 4.4 show alternative responses to an interruption in the innovation system. Figure 4.5 plots how the size and performance of a sectoral innovation system in a country changes over time as a result of learning within the system, interruptions and radical institutional changes. The trajectory of a country is indicative of the way its

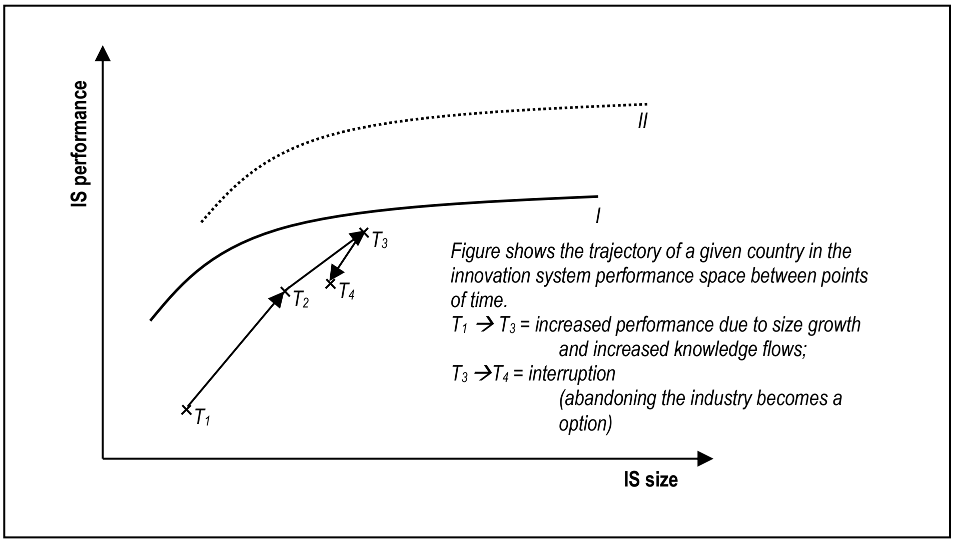
[61] Here we are primarily referring to radical technological changes at the frontier which pose challenges to a latecomer that is trying to close the technology gap. But of course, this is not necessarily the case. If the latecomer is not catching up and the technology gap is not being closed, even incremental change at the frontier can cause the latecomers's knowledge base to become obsolete.

DOI: 10.14267/phd.2016013

institutions function and reveals the major constraints to and opportunities for industrial competitiveness, related to the functioning of the innovation system.

Figure 4.3 represents the case of a latecomer industrialiser that fails to make the transition to a new system of innovation. As resources available for the sectoral innovation system increase, its actors learn to utilize the institutional setup to reach near-frontier performance with their interactions. The system will move closer to the frontier (movement over time from T_1 to T_3). What happens when the system reaches the frontier? Assuming that its aim is to increase performance, staying on a frontier where the returns to additional resources decline to zero, would marshal *internal* forces for institutional change.

Figure 4.3 Interrupted Innovation



Source: author's compilation

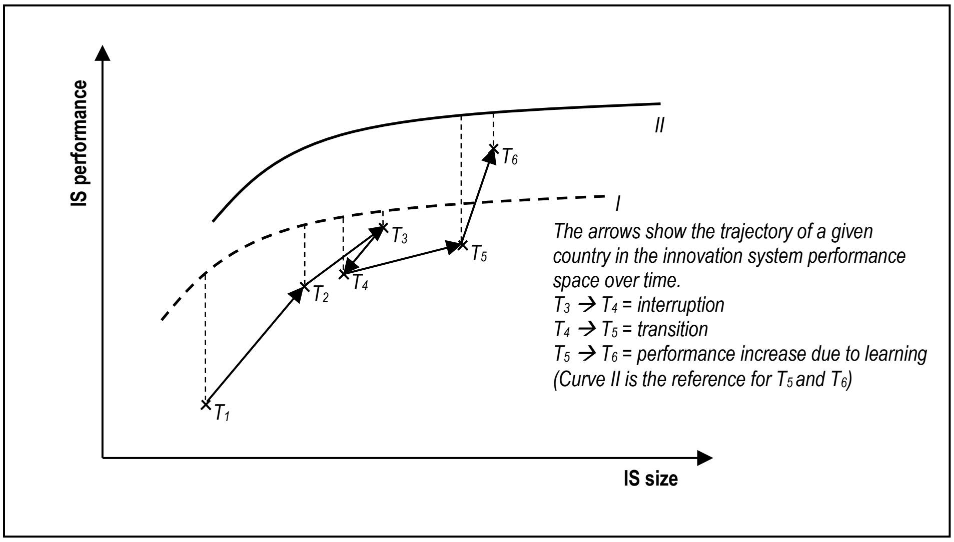
If these changes could be realized in a short time, the sectoral system could smoothly jump to a new growth path without significant performance loss and any further increase will be relative to the new performance frontier.

But such a smooth transition is very unlikely in an industry prone to huge sudden fluctuations in demand. A decline in demand will indirectly result in shrinking resources available for innovative activity, which provides an *exogenous* shock to the innovation system. Thus the system is faced with a double challenge: changing external circumstances and diminishing returns to investment in innovation within the existing system. The innovation system's performance will decline and an interruption occurs. This is illustrated by the movement from T_3 to T_4 in Figure 4.3 .

DOI: 10.14267/phd.2016013

Should the drop in innovative performance in a latecomer country become too big and should the chances to mobilize resources for a recovery be too dim, the interruption may result in the abandonment of further efforts to develop this industry. Both the innovation system and the productive system will collapse. The emergence of an aerospace industry has then failed.

Figure 4.4. Interruption followed by successful transition to a new innovation system

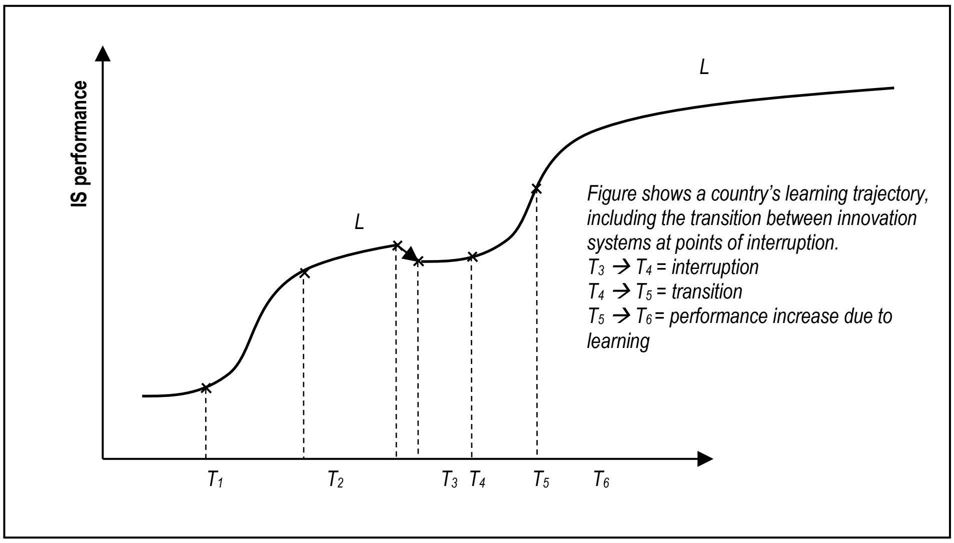


Source: author's compilation

Figure 4.4. shows the case of a successful transition to a new system defined by frontier curve *II*. Recovery after an interruption will not immediately show higher performance even if a successful transition to a new system of innovation has been achieved. Increased performance can only be realized over time as the actors learn how to achieve best practice relative to a new performance frontier. Note that at T_5, the new system will not necessarily be performing better than the old one at T_3. The new system will only start to perform better than the old one as the actors learn to work the new system and we approach T_6.

DOI: 10.14267/phd.2016013

Figure 4.5. A learning trajectory: interruption and successful transition



Source: author's compilation

In Figure 4.5., we plot innovation system performance of a country against time on the horizontal axis, rather than against innovation system size as in the previous figures. Here, the development trajectory *of a successful transition from one innovation system to another* will take the form of a set of S-curves. Up to the point of interruption, the industry follows a learning curve in its attempt to approach frontier performance. The interruption results in an abrupt decline in innovation performance.

In Figure 4.5., *L* refers to the actual learning trajectory of the country (frontier performance is not reproduced here). The interval T_1 to T_3 refers to the learning curve of an emerging system prior to the first transition. T_3 to T_4 refers to an interruption. T_4 to T_6 refers to the successful transition from the innovation system with performance frontier *I* to a new innovation system with a performance frontier curve *II*. At T_6 we see the beginning of a new learning curve.

In the interruption period $T_1 – T_4$ there is a crucial challenge for the relevant actors to react to the crisis by reconfiguring the institutions in an innovation system and possibly expanding it with new resources. This is necessary in order to redirect learning efforts onto a trajectory that produces the supply of innovations required by the changed demand conditions facing the industry. After the system transition, the actors in the sectoral system of innovation try to move towards a new performance frontier, hence the emergence of a new S-curve.

DOI: 10.14267/phd.2016013

The time between the point of interruption and that of system change depends on the readiness and capability of the actors to react to changes in the environment. It is thus an indication of the flexibility and adaptability of the innovation system of an industry.

A crucial difference between well-established or mature innovation systems[62] and emerging ones is the greater vulnerability of emerging innovation systems to external shocks. These shocks cause interruptions during which previously acquired technological capabilities are lost. Even leading producers have found to be prone to ‘organizational forgetting’, but to a lesser extent that latecomer producers.[63]

4.1.5 System performance and competitiveness

The long-run competitiveness of a high-tech industry depends on the capacity of its sectoral innovation system to provide cost-reducing and productivity-increasing innovations and new products with technological features superior to those of its competitors. How does competition feature in our framework?

Competition is a key driver of improvements in innovation system performance. Suppose that industries from two different countries competing to supply the same market face similar frontier curves for innovation performance. The industry that is closer to the frontier has a higher propensity to innovate; hence a higher chance to be more competitive in a knowledge-based industry.

However, the performance frontier curves differ from country to country. Countries may not only compete in their relative distance from a given innovation performance frontier, but also in the position of the frontier itself (e.g. innovation frontier *I* and innovation frontier *II* in Figure 4.4.). They can increase their competitiveness in two ways. First, by learning within a system, what corresponds to moving closer to an existing performance frontier as shown in **Error! Reference source not found.**. Second, by making the transition to a radically new performance frontier which is superior to the previous one (Figure 4.2).

This implies two different kinds of costs: first, the learning costs associated with narrowing the distance to the frontier; and second, the transition costs from one frontier to another. These costs have to be borne by the entire innovation and production system. Only if the industry is selling competitive products can these costs be recovered. A key dilemma for the governance of innovation systems is to find the most cost-efficient way

[62] Chaminade and Vang (2008) use the term ‘mature innovation systems’.
[63] Production experience can depreciate, not only appreciate over time (Benkard, 2000)

DOI: 10.14267/phd.2016013

to manage system transitions. Incremental changes will not bring about as great gains as radical ones, but the costs of radical institutional changes may well be high. Path dependence, the comfort of established routines, the lack of information about the alternatives, the uncertainty concerning outcomes of institutional change reduces the likelihood of the occurrence of major institutional changes.

Finally, there is another element of competitiveness: the speed of reaction to global declines in the demand for aerospace products, in case of crises. Competitiveness in these instances is measured by the flexibility of the industry, or its ability to respond in a timely fashion to the changing demand conditions by changing its institutions. McKelvey et al (2006a,b) discuss rigidity and flexibility of innovation systems and identify the period of *adjustment* to new demand conditions (both external and internal to the industry) critical moments.[64]

4.1.6 External causes of interruption

A major difference between innovation system change at the technological frontier and innovation system change in latecomer countries is the most likely cause of interruption. Latecomers by definition enter an industry characterized by Schumpeter Mark II competition[65] and focus their learning efforts on acquiring and improving already proven technologies. This entails investment in physical and human capital which, especially during the early phases depends on the government's financing abilities. Consequently macroeconomic and political crises and changing competitive environments are all potential external causes of interruption and have a far greater likelihood of causing interruptions than endogenous technological factors.

4.1.7 Questions for case studies

Times of crisis offer ideal points of entry to observe innovation system change. The drop in demand puts both the production and the innovation systems to a test. Since it jeopardizes survival, it triggers responses from the system. As pointed out earlier, crises are cyclically returning challenges in the aerospace industry, and stakeholders need to be prepared for slumps and need to learn how to respond and find innovative solutions

[64] Also at firm level, Yuan et al (2010) showed that strategic flexibility matters; it is reasonable to assume that a first mover advantage exists when it comes to competition between firms. The producerthat first embarks on the new innovation path has the highest likelihood of recovering from a major interruption.

[65] 'Schumpeter Mark II' refers to a consolidated structure where a few large firms make benefit of economies of scale and finance R&D investments to maintain their leading position (Nelson and Winter, 1982 and Malerba and Orsenigo, 1996).

DOI: 10.14267/phd.2016013

to weather the crises and set the industry on a growth path more rapidly than its competitors.

In the following section we present five country case studies of how crises triggered changes in of the sectoral innovation systems in the aerospace industry. The cases are those of Brazil, China, Indonesia and Argentina. The first two cases are cases of successful development of the aerospace industry in a developing country context. The last two cases are cases where the aerospace industry has so far failed to take off.

Based on the conceptual framework of interrupted innovation developed above, we examined the following analytic questions in the country case studies:

1. What trajectories did the latecomers in aerospace follow? (How can these trajectories be measured and analysed? To what extent is the end of the emergence phase associated with interruptions and transitions?)
2. What caused the interruptions in the development of the sectoral innovation system? What is the balance between internal endogenous sources of interruption and exogenous system shocks?
3. What were the characteristics of the transition period? (How did interruptions and transitions affect the accumulation of latecomers' technological capabilities? Which actors governed the transition periods, and what factors contributed to the success or failure of transition from one innovation system to another?)

4.2 BRAZIL

4.2.1 Introduction

The aircraft industry of Brazil has received more attention than that of any other emerging economies. This is not surprising, since its flagship company, Embraer has made it to the top three companies producing commercial aircraft, and has been among the top five manufactured product exporters of Brazil. This case shows that Embraer's years of success and failure were all closely linked to the performance of the Brazilian sectoral system of innovation in aerospace.

We provide a detailed historical overview of the origins of aircraft manufacturing in Brazil in the 1930s and 1940s and the associated innovative activities, of the emergence of a new innovation system in the 1950s and 60s, of the subsequent growth period led

DOI: 10.14267/phd.2016013

by a state-owned enterprise, the crisis years of the early 1990s, the transition to a new system along with the privatization of Embraer, until the crisis in the first decade of the new millennium.

4.2.2 The origins of aircraft manufacturing in Brazil

The development of the Brazilian aircraft manufacturing industry during the Embraer era has been studied extensively (Sarathy 1985; Cabral 1987; Mowery 1987; Ramamurti 1987; Frischtak 1992, 1994; Cassiolato *et al.* 2002; Goldstein 2002a; Marques 2004). However, the origins of aircraft manufacturing on an industrial scale and the origins of an aerospace innovation system date back to decades before the foundation of Embraer.

The 1930s brought about accelerated industrialization in Brazil in a wide range of sectors, including airplane production. This was a departure from earlier experimental efforts of pioneer aviators such as Santos Dumont, since it now involved serial production. Industrialists, the military as well as the administration of Getulio Vargas saw potential in larger scale aircraft production. Antonio G. Muniz, a military official and aircraft designer trained in France emphasized the benefits of locally training engineers. He argued that establishing research, design and manufacturing capabilities would reduce dependence on foreign countries (Viegas 1989).

One of the first aircraft manufacturing companies, the Fabrica Brasileira de Aviones (Brazilian Airplane Factory, FBA) was a subsidiary of the air transport company[66] owned by the entrepreneur Henrique Lage. The FBA was established in Rio de Janeiro and designed a dozen of aircraft for aero clubs and the military using the skills of Muniz and Belgian and French engineers. Between 1936 and 1948 over 200 aircraft were built (See Table 4.1).

The approach of World War II increased demand for aircraft. The FBA received a number of military launch orders, but same models were also sold to civilian aero clubs. Meanwhile, production facilities were set up at the Fabrica do Galeão in Rio de Janeiro with German technical assistance to produce Focke-Wulf trainers under license.[67] Brazil's shift from a German orientation to the Allies brought along changes in aircraft production. The Fabrica do Galeão was selected to produce the Fairchild PT-19 trainers

[66] The *Companhia Nacional de Navegação Aérea* (National Air Navigation Company, CNNA), 1935.
[67] Two models, the Fw 44 and 58 (local designation 1 FG and 2 FG) were produced with 40 and 25 pieces during 1940-42.

DOI: 10.14267/phd.2016013

under license (local designation 3 FG). During 1942-43 the factory produced on average 116 of these planes.

Table 4.1 First series production of airplanes in Brazil, 1936-51

Year	Model	Designer	Manufacturer	Nr. produced
1936-41	M-7	Muniz / Henrique Lage	Fabrica Brasileira de Aviones / CNNA	26
1939-43	M-9	Muniz / Henrique Lage	Fabrica Brasileira de Aviones / CNNA	40
1940-41	HL-1	Muniz / Henrique Lage (Piper)	Companhia Nacional de Navegação Aérea	108
1942-48	HL-6	Muniz / Henrique Lage	CNNA	60
1940-42	1 FG	Focke Wulf Fw-44)	Fabrica do Galeão	40
1940-42	2 FG	Focke Wulf (Fw-58)	Fabrica do Galeão	25
1942-43	3 FG	Fairchild (PT-19)	Fabrica do Galeão	232
1942-43	CAP-1 Planalto	Grupo Pignetari	Companhia Aeronautica Paulista	9
1945	CAP-3	Grupo Pignetari	Companhia Aeronautica Paulista	8
1943-48	CAP-4 Paulistin ha	Grupo Pignetari	Companhia Aeronautica Paulista	777
1946-51	T-6	Texan (license)	Lagoa Santa/Companhia Aeronautica Paulista	81

Source: Cabral (1987) Tab. II.1. and Viegas (1989)

There were a number of other companies trying to enter aircraft manufacturing. The Empresa Aeronáutica Ypiranga (EAY) was set up in 1931. The company intended to produce glider planes and copied two German models of which only a few were manufactured. There was another design that was very influential: the EAY-201, a single engine, two-seater plane with wings placed high, based on the successful US model, the Taylor Cub. Interestingly, EAY, the innovator, did not have much success with the plane. It eventually sold the designs to *Companhia Aeronautica Paulista* (Aeronautical Company of Sao Paulo, CAP).

CAP was founded in the state of Sao Paulo as the aviation section of the Pignatari Group in 1942. This company commenced operations with the production of a successful German model, the *Alcatraz*, and the *Saracura* before producing a locally designed 2-seater, single-engine plane, the CAP-1 (and a more advanced CAP-3) "*Planalto*". Including the prototypes, around 20 of these planes were built. CAP quickly accumulated manufacturing capabilities which proved to be most successful when it acquired the manufacturing rights for the EAY-201 model from the Ypiranga company. After a few modifications the CAP-4 *Paulistinha* became the best-selling Brazilian plane of its time. A total of 777 planes rolled out of the plant at Santo André between

DOI: 10.14267/phd.2016013

1942 and 1948. Except for the engines, the *Paulistinha* was made of Brazilian materials and parts and has also been exported to South American countries and Portugal. CAP never managed to develop (or acquire) a successful model after the *Paulistinha*, despite efforts to design modified versions. The end of the war brought the end of the company as well. The decline in military orders and the dumping of cheap second hand North-American planes on the Brazilian market resulted in the closure of the plant in 1949.

The Brazilian aircraft manufacturing capabilities of the 1940s were far behind the capabilities of European or US plane makers of the era, but they still managed to sell their planes due to the wartime demand for "anything that flies". The technology gap became apparent in peacetime. The numerous commercial airlines of Brazil (Aerovias Brasil, Cruzeiro do Sul, Varig, VASP)[68] flew medium sized and larger propeller planes (DC-3s, DC-4s, Junkers Ju 52, Convair 240s, Lockheed Super Constellations) and even jets from 1959 (Caravelles and later B-707s). The small planes built in Brazil had no market outside flying clubs.

The industry was entering a long decline period during the late 1940s. Postwar periods pose a reorganization challenge for industries, a need to shift from quantity-to quality oriented production during times of "demobilization instability" (Higham 1968). The end of World War II offered a moment for Brazil to reconsider the strategies concerning the aeronautical industry. The transportation infrastructure was underdeveloped, especially in the vast continental lands of Brazil. Air transportation and supplying industries had a huge potential, but also required infrastructural investments.

4.2.3 The emergence and growth of a sectoral innovation system

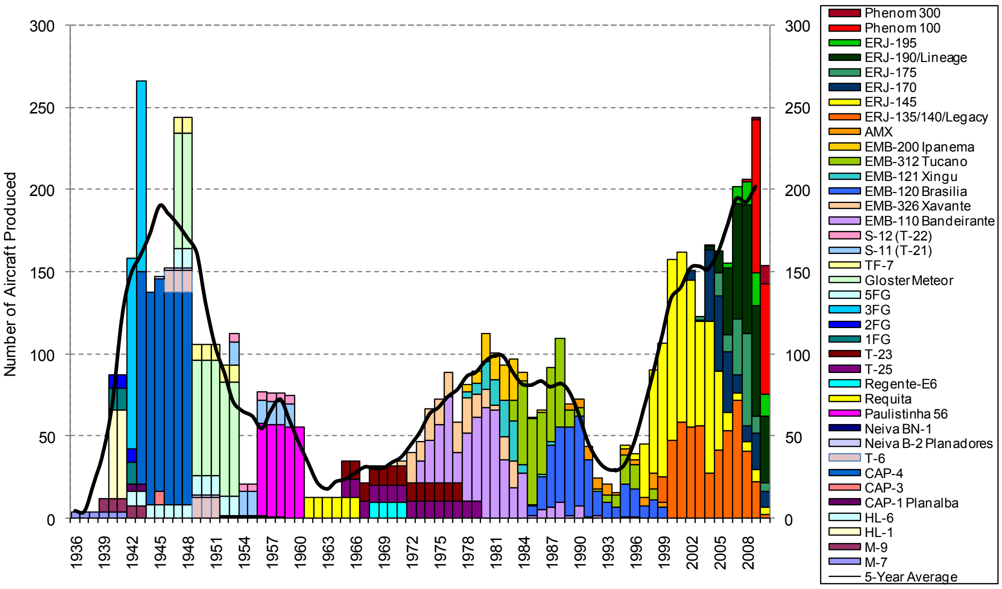
The long transition period over the 1950s and 60s until the establishment of Embraer marks a crisis in the industry, but also the emergence of a sectoral innovation system. As Figure 4.6 shows, no significant new products were launched. Production involved small planes representing older technology. Why did it take over 20 years before a new company could emerge from the ruins?

There was no overarching strategy on how to develop the sector. The government's hesitation to outline any strategy and appropriate large sums in the budget for indigenous aircraft development appeared to be vindicated by the failure of aircraft

[68] Many of these originated from before the WWII when they were only providing domestic services. Between the two world wars, airlines associated with European governments were fighting for a leading position in the Trans-South-Atlantic passenger and mail services. For a thorough account of the fierce competition even within French companies, see de Bure (2006).

development projects in neighboring Argentina. Competing with foreign producers in the commercial air transport market was far beyond the financing ability of local entrepreneurs. Before the war, previous experience in the steel or automobile industries sufficed to produce simpler small planes, but more sophisticated products required a larger pool of aeronautics engineers, technicians and physical capital investments. Industrialists instead focused on serving the general aviation market. A famous entrepreneur of the time was José Carlos de Barros Neiva, who founded a homonymous company in Rio in 1954 and manufactured glider planes. Two years later the company moved to Botocatu and produced the *Paulistinha* and *Regente*, for which it acquired licenses. Although it did roll out a trainer for the air force which was its own design, Neiva remained the producer of gliders, single-engine general aviation or agricultural planes, and later a component manufacturer of Embraer (which eventually acquired it in 1980 following financial difficulties).

Figure 4.6 The evolution of aircraft production in Brazil, 1936-2010



Source: own compilation based on Cabral (1987); Cassiolato *et al* (2002), Embraer Annual Reports, The *Airlinerlist* database <http://www.airlinerlist.com> (downloaded 2009 Feb); and *Flight International*, various issues.
Note: Since exact annual production is unknown before 1969, the total number produced was spread evenly over the estimated years of production. Figures after 1970 exclude new general aviation aircraft production runs, among others the license-produced Pipers and the upgraded versions of the *Ipanema* (EMB-201 and 202).

The government did not invest in major aircraft development projects, but it did agree to finance the education and training of aeronautical engineers and technicians. Specialized training was already available at the army's technical school established in

DOI: 10.14267/phd.2016013

1939, and at the *Escola de Aeronáutica* (School of Aeronautics Engineering) at Campo dos Afonsos in Rio de Janeiro.[69] In 1946 this was transformed into the *Instituto Tecnologico da Aeronautica* (Aeronautics Technology Institute, or ITA in short), which became the "alma mater" of all the key persons in the sectoral innovation system.[70]

Between the two most influential cities, Sao Paulo and Rio de Janeiro, Sao José dos Campos, a town in the Paraiba valley was chosen as the strategic location[71] for the newly established *Centro Tecnico Aeroespacial* (Aerospace Technical Center, CTA). As a branch of the military, CTA was inaugurated in 1950 to conduct and oversee research in aviation and space flight in Brazil. It offered post-graduate research positions for engineers from ITA, especially in the *Instituto de Pesquisa e Desenvolvimento* (Research and Development Institute, or IPD). IPD was one of the four institutes subordinated to CTA, as was ITA which was moved to the grounds of CTA. The two other institutes apart from ITA and IPD were the Institute for Space Activities and the Institute for Development and Industrial Coordination.

It was IPD's mission to develop aircraft locally. It housed several promising experimental projects, including a vertical take-off aircraft and the *hummingbird* helicopter involving experienced German engineers. However, neither of the two projects advanced to commercialization because of design failures. Other projects were more successful and CTA followed a strategy of spinning them off into aircraft producer companies. The air force ran CTA, but was not commercializing the results of development projects. Aerotec, one of the first spin-offs, was founded in 1962 to produce the *Uirapuru* for air force to replace its aging Fokker trainers (150 planes between 1968 and 1977). The most famous spin-off company was Embraer, which was a result of a transport aircraft development project.

The story of Embraer began when the Brazilian Air Force (FAB) commissioned CTA to develop a twin-engine, non-pressurized 8-10 seater turboprop transport. IPD launched the '*IPD-6504*' project under the leadership of air force officer and

[69] Colonel Casimiro Montenegro Filho played a crucial role in its foundation.
[70] "ITA was inspired by the MIT model and in fact, a number of professors from the Aeronautics department of MIT (as well as German engineers) went to work at ITA in the early years. By 1988 ITA had trained more than 3000 engineers, 800 of which were in the aeronautics field" (Frischtak 1992, p.5)
[71] Motivations for selecting Sao Jose are numerous, including favorable climate and topographical conditions, the accessibility to energy and means of communications, the relative remoteness from urban centers while being not too far from Sao Paulo (with the newly built President Dutra highway providing easy access to Sao Paolo) and the possibilities for further growth.

DOI: 10.14267/phd.2016013

aeronautical engineer Ozires Silva.[72] The celebrated French aircraft designer, Max Holste was hired to lead the design work. The prototype of the *IPD-6504* successfully accomplished its maiden flight in October 1968. But it took substantial organizational efforts to transform the prototype into a product later known as the *Bandeirante* and required entrepreneurial skills on top of technical skills, and no company in Brazil possessed the capabilities to manage a commercial aircraft producing venture.[73]

The commercialization of the IPD-6504 project did not go to existing companies, because both Neiva and Aerotec found the endeavor too risky, fearing too high dependence on government contracts[74]. Even the Dutch manufacturer Fokker turned down the offer. Silva (2002) noted that given the risk-aversion of Brazilian private investors, the only solution was to create Embraer as a state-owned enterprise in 1969. Many of the later observers overlook the fact that if it wasn't for the entrepreneurial designers, the military government would not have pushed for establishing a commercial company. Instrumental in this endeavor was the "social capital" (in the sense of Akçomak and ter Weel (2009) of Silva and other members of the team. By the end of the 1960s, members of the class graduating from ITA in 1962 had already established key positions in the administration and in the military. It is also interesting to note that Embraer developed a corporate culture that motivated employees despite their relatively low financial compensation. Embraer was also working on another spin-off project, a small agricultural airplane, for which the funding came from the Ministry of Agriculture. The EMB-200 *Ipanema* became the most successful single model of which over a thousand has been produced (and is still in production, certified also to consume ethanol in 2004).

The *Bandeirante* prototype that flew in 1968 underwent a number of modifications in size and performance before certification and the finalization of the serial production design at the newly founded test facilities of Embraer. The final commercial version

[72] In 1965, a group of engineers from CTA were investigating the causes of another accident in the interior of Brazil. Among them was Silva, an outstanding graduate of the Escola de Aeronáutica and ITA (and later of Calthech). Silva recalled in an interview (Silva, 2009) that it was during this investigation when he realized that there was a market niche for smaller transport aircraft with lower servicing and airport infrastructural needs. The number of towns with operating airports had sharply decreased in preceding years (from a height of 360 to only 45 in 1956). The potential replacement models for the aging planes servicing these small airports (mostly DC-3s) required more sophisticated airport infrastructure. Brazil eventually chose a path to develop an aircraft instead of spending on the development of a large number of airports.

[73] Max Holste for instance was skeptical of the project's success and left the team for Uruguay.

[74] Neiva had been following the *IPD-6504* project from the very beginning, and even arranged the historic meeting between Max Holste and Ozires Silva, as the latter recounted in his memoirs (Silva 2002).

DOI: 10.14267/phd.2016013

was a 19-seater model, of which a total of 500 planes were produced between 1972 and 1990.

The task to mass produce commuter airplanes required capabilities that did not exist in Brazil. So far, CTA had successfully accumulated the capabilities to absorb technology by establishing a strong engineer training program at ITA, by cooperating successfully with foreign institutes (MIT), scientists and engineers. But no Brazilian enterprise had experience in producing and selling commuter planes to airlines. Frischtak (1992, p.17) and Moxon (1987) note that Embraer chose a unique development trajectory as it skipped the step of locally assembling planes under license. This is true to the extent that Embraer and the government of Brazil did cooperate when it came to targeting capabilities required to fill gaps in the capabilities.

The entire innovation system responded in a very flexible way: the channels among the different actors were open, open also to reach out to and include new actors. First of all, the military (after some persuasion) provided the source of finance through a military commission for the production of 80 *Bandeirantes*. Apart from the labor force trained at ITA, the required technical knowledge for mass-production was furnished from external sources. One of the most important sources was a licensing agreement with the Italian manufacturer Aermacchi on the production of *Xavante* (EMB-326), a jet trainer and fighter.[75]

Aermacchi designers were physically present in Sao Jose dos Campos to provide assistance with design of certain parts and solving various tasks; it was a 10 years deal that followed through the whole learning curve of Bandeirante production. Another source of technological know-how was an offset contract with the American company Northrop. While procuring 50 F-5s for the Brazilian Air Force, Embraer was commissioned to produce vertical fins, rudders, wings and belly pylons for a 100 of this model. It provided Embraer with technologies such as chemical milling, metal-to-metal and honeycomb bonding as well as working with composite materials.[76]

[75] Ramamurti quoted Pessotti, Embraer's technical director: *"It was a very interesting cooperation, because it brought a lot of technology and expertise that we did not have at that time in Brazil – for example, in areas such as tracing technology, assembly of planes, organization of procurement of materials, quality control, technical documentation, organization of assembly lines, etc."* (Ramamurti 1987, p.185).

[76] "In addition, the contract also forced Embraer to improve on its tool design, quality assurance and other production techniques, while stimulating the use of numerically-controlled machine tools" (Frischtak 1992, p.18).

DOI: 10.14267/phd.2016013

A major foreign source for marketing, sales and support know-how was the "collaboration" with US general aviation producer Piper. The process through which the Brazilian government selected Embraer's collaborating partner was more an ultimatum than a real competitive deal. As a result of the economic boom of the early 1970s demand for small planes grew substantially[77], and as a result of the foreign exchange crisis following the oil crisis of 1973, the government was ready to bring production of these planes to Brazil – to Embraer. It followed a strategy of giving monopoly licenses to one producer and deterring imports from all the others. The deal offered to three top US general aviations producers was as follows: (1) allow Embraer to progressively manufacture a greater share of the planes' components and parts in Brazil; (2) do not oblige Embraer to pay any royalties; (3) allow Embraer to make modifications on the models; (4) expect collaboration on future aircraft design, production and marketing. Despite being the biggest exporter to Brazil, Cessna was opposed to most of the demands so an agreement was concluded with the most cooperative company, Piper. As promised, import taxes on planes for general aviation were raised from 7 to 50 percent in line with the new import substitution policy. Over the years, from 1975 Embraer produced thousands of Piper models (under local names and designation: EMB-710, -711, -712, -720, -721, -810 and -820).

The rather flexible response and reorganization of the innovation system to accommodate mass production owes much to the cooperation of a number of actors, who were all motivated by the vision of creating a functioning aircraft industry in Brazil. Institutional actors, companies, government agencies in the country were dominated ultimately at the individual level by ITA graduates who were ready to cooperate in their various specialized positions. Coordinating all these actors and having strong negotiating powers vis á vis external actors was the Ministry of Aeronautics. The ministry did not shy away from implementing protectionist trade agreements and providing support to Embraer in a various ways, be it technical, financial, marketing or regulatory assistance. Embraer was also given preferential treatment, and was exempted from import taxes and duties on materials, parts and components that were not available locally.

The government also played a crucial role in providing finance. First, by controlling 51 percent of the so called 'voting shares' of Embraer; second, indirectly, by

[77] Import from the US was 540 planes in 1974 in the value of 150 million USD (Ramamurti 1987, p.190)

DOI: 10.14267/phd.2016013

establishing a tax incentive scheme that solved the problem of the unavailability of venture capital and making it interesting for private companies to own a share of the new state-owned enterprise. Companies (of all sizes, ranging from large state-owned enterprises to SMEs) could invest every year up to 1 percent of their federal income tax in Embraer shares – on which they could even receive dividends (which they in fact received from 1974 onwards). These preferential shares were nonvoting shares. Thus they did provide influence on company decisions (the government always maintained at least 51 percent of the votes), but they did bring in substantial amounts of capital. Ramamurti (1987, pp.192-4) shows that the government's share in total equity fell from 82 percent in 1970 to 7 percent in 1981. Additionally, Embraer received further support from the air force through procurements and direct R&D support.

Why did the *Bandeirante* succeed? All the efforts to enter the phase of mass production would have been in vain, if Embraer had not rolled out a model that actually responded to a market needs. The *Bandeirante* was capable to operate in extreme conditions, with minimal ground support and low maintenance requirements and with a flexibility of configurations. All this was provided at a very competitive price, a rather fast (45 day) delivery time and appealing financing conditions (9 percent interest rate as opposed to almost double that amount offer by US competitors). The only disadvantage compared to similar models was higher fuel consumption and shorter range.

The success in finding a niche market explains a lot of the success of Bandeirante. Kimura (2006) shows how a commercial aircraft development project failed in Japan after the Second World War. Driven partly by the same need to replace aging DC-3s, partly by national pride and nostalgia, the public-private consortium NAMCO developed a 64-seater turboprop airliner, the YS-11. The cooperating companies (Mitsubishi, Kawasaki and Fuji Heavy Industries) developed significant technological capabilities in aircraft manufacturing, and 182 planes were sold until the project was terminated in 1974. But the project was a commercial failure; the plane was obsolete by the time it was introduced. It was competing in a market segment that was being taken over by jets. As a result, the Japanese industry had to transform and gain competitive competences in component manufacturing. The similarities between the Brazilian and the Japanese endeavors are striking: both countries had experience in large scale production of planes during the war, but production was discontinued after the war. Both countries saw the strategic significance of the aircraft industry, leading to significant government investments into R&D and a high reliance on initial military

DOI: 10.14267/phd.2016013

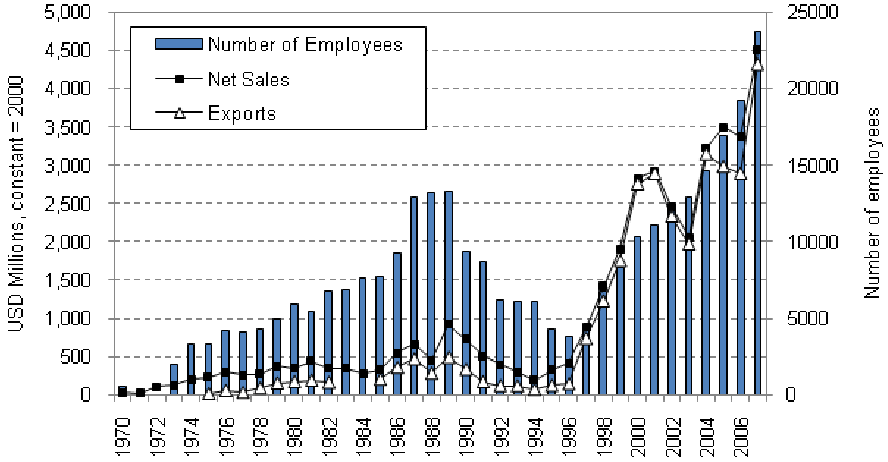
procurement at the start of production. Both countries were facing the high prices of late entrants: a steep learning curve, high development costs. But while Japan chose the path of indigenous production, Brazil successfully invited foreign experts and paid close attention to market demands.

Internationalization of sales was the natural way of securing sales. Serving the American market was already a strategy in mind at the design phase of the *Bandeirantes*.[78] Following the oil crisis, airlines in the US showed great interest in the newly developed plane. But it took quite some diplomatic efforts by Brazil to finally receive the FAA certification in 1978, due to strong objections by US producers who were lobbying for retaliation against the discriminatory import tariffs imposed by Brazil. By then, the plane had received foreign certifications in a number of countries and was sold to Uruguay (1975) and France, the United Kingdom and Australia (1977). The most important market turned to be the United States. The timing of the entry was well chosen, as it also coincided with a deregulation of the US market in 1978, which resulted in the closure of jet service to smaller airports, thus opening a niche for shorter and cheaper commuter service by turboprop planes. An additional feature making the *Bandeirante* cheaper to operate was its 19-seater configuration, since planes above 20 passengers were supposed to have an additional flight attendant. The market expanded fast, but Embraer was among the first movers. The only US-made direct competitor was the Fairchild *Metro III*. To meet the increased demand, the production of the *Bandeirante* reached a rate of over 5 planes a month in 1980 and 1981. Exports amounted to nearly 50% of total sales in these years and, (102.7 million USD in 1981).

[78] According to Silva (interview, 2009), instead of responding to the request of Brazilian associations to have the metric system on board, they implemented US standards.

DOI: 10.14267/phd.2016013

Figure 4.7 Embraer's sales, exports and number of employees, 1970-2007 (Million USD at constant = 2000 prices)



Sources: Embraer, Frischtak 1992, Ramamurti 1987, Cassiolato *et al.* 2002.

To sum up, during the 1950s and 1960s the basic elements of an emerging sectoral innovation system were established. The emergence of its main actors and linkages happened slowly and without a clear central mission. Investment in aerospace education and research provided an important breeding ground. A sectoral innovation system emerged slowly, and in it entrepreneurial engineers played a crucial role as "system brokers". The system broker, Ozires Silva[79] and his team at CTA played a central role in (1) finding a market niche (commuter aircraft capable of serving airports with poor infrastructure); (2) channelling finance and design efforts to successfully develop a new product for this niche (IPD-6504); (3) establishing a company to ensure commercial valorisation of innovations (Embraer, 1969); (4) creating new linkages to provide capital (government launch support, government commissioning of 80 *Bandeirantes* and subsequently new planes, and a corporate tax incentive scheme channelling private capital to Embraer) and (5) creating linkages to access technology (through an exclusive contract with Piper, a deal with Italian producer Aermacchi, an offset contract with Northrop and collaboration with the Canadian engine manufacturer Pratt & Whitney).

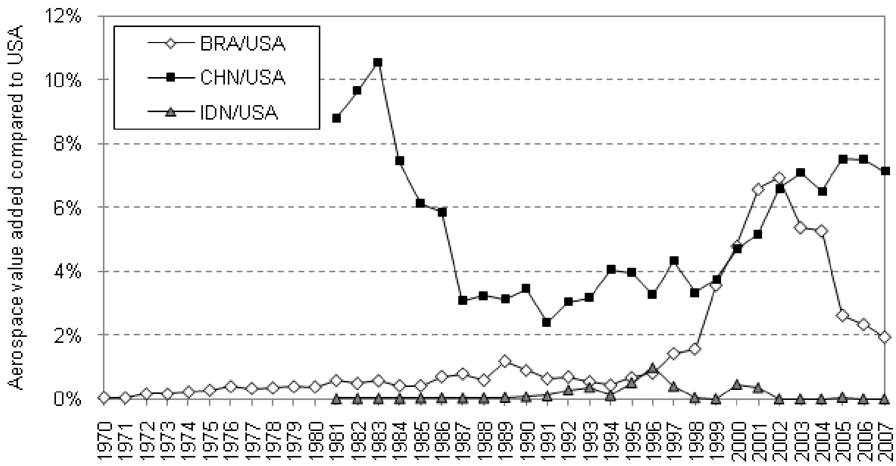
The empirical evidence of successful system transition is ample. On the output side, Figure 4.6 shows the production cycles of major new products: the EMB-110 *Bandeirante* 19-seat commuter plane, the EMB-312 *Tucano* (single-engine military basic trainer), the EMB-121 *Xingu* (a pressurized executive twin-turboprop), and the

[79] An air force pilot, ITA (and later Caltech) graduate aeronautical engineer, founder and president of Embraer (1969-86), who also played a key role in its privatization in 1994.

DOI: 10.14267/phd.2016013

EMB-120 *Brasilia* (a pressurized 30-seater twin-turboprop commuter). Figure 4.7 shows the increase of sales revenues of Embraer (to a historical maximum of 924 million USD in 1989) and the growth of exports (nearly two-third of sales revenues by mid-1980s; growing to 486 million USD in 1989). This shows that Embraer's strategy of aiming at the commercial commuter market[80] paid off, especially after the liberalization of the US market. In 1981, *Bandeirante* had a 37.8% share in the 15-19 seat segment (Sarathy 1985). Brazilian aerospace value added grew to 220 million by 1980 and 790 million USD by 1989. This growth is especially remarkable when contrasted to the global industrial landscape, shaken by the oil crisis of 1973. Brazilian growth in aerospace was nearly 10-times the growth of the global industry (in capitalist economies) during the 1970s. Even after the start-up decade, the 258% expansion of production between 1981 and 1989 still overshadows the global average expansion of 122% (and 125% of the USA), providing a clear evidence of catch-up (Figure 4.8).

Figure 4.8 Trends of catch-up: aerospace value added of Brazil, China and Indonesia compared to the US, 1970-2007 (%)



Sources: Chinese National Bureau of Statistics, IBGE, UNIDO. See Appendix A.1.

We argue that the emergence of the innovation system and its institutional set-up was a necessary precondition for the accelerated growth of the industry. We do not debate the crucial role of Embraer's management in successful formulating and executing a sound strategy for increased sales performance and growth. However, the physical and human resources and the general institutional arrangement for performing innovative activities

[80] Already at the development of the *Bandeirante*, US FAA guidelines were fully observed to facilitate certification, which is essential for exports. Airworthiness certificate was given by France in 1977, by the UK and the US in 1978. Feedback from regional airlines and other users was considered seriously for the development of subsequent models.

DOI: 10.14267/phd.2016013

were available before the creation of Embraer. The government and other systemic actors provided key elements such as an affordable supply of skilled labour, R&D activities (results of which Embraer commercialized), openness to foreign technological sources, military procurement to support new aircraft development, export credits and protectionist trade policies.

The establishment of Embraer as a state-owned enterprise[81] was the final institutional innovation in the formative phase of the sectoral system of innovation (SSI). A national champion allowed Brazil to reap the benefits of an already existing SSI and to set the forces of innovation in motion. It was a necessary condition for the increase of innovative performance, since much of the tacit knowledge required for competitive production based on up-to-date technology needed to be acquired through ‘learning by doing’.

State ownership did not preclude the Embraer management from governing certain functions of the innovation system. The successful emergence of the Embraer-championed aircraft industry in Brazil – what Ramamurti (1987) aptly refers to as a combination of public power and private initiative – was in fact the result of shared governance of the innovation system. Following the typology of Hekkert *et al.* (2007), certain functions such as ‘knowledge development’ and ‘knowledge diffusion’ were shared between CTA and Embraer’s R&D departments or foreign sources. ‘Guidance of search’ for new technologies and ‘market formation’ were jointly influenced by the marketing strategy of Embraer and the procurement policies of the Air Force and the Aeronautical Ministry. The government played a decisive role (especially at the beginning) in ‘resource mobilization’ (including capital, skilled labour and technology). Embraer (and other smaller companies) provided ‘entrepreneurial activities’ for the system.[82]

This governing structure remained in place until the next major transition of the SSI. Over the years as production increased smaller adjustments were made in the institutional framework (often to meet the needs of Embraer). This indicates an incremental ‘co-evolution’ of technology, institutions and organizations. However, the performance of the innovation system increased and so did its size, without any significant trend break.

---

[81] State ownership was a last resort to overcome the lack of private venture capital (Silva 2002)

[82] It is an interesting problem whether the emergence of a system broker was a historical accident or whether it was a product of the system. We argue that the more advanced the educational and research organizations are in the system, the higher the chances for entrepreneurs to emerge.

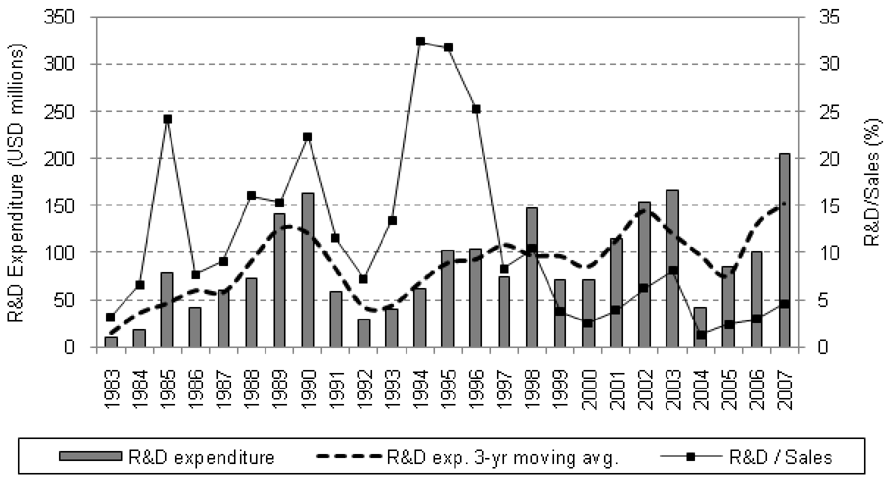
DOI: 10.14267/phd.2016013

4.2.4 The Crisis of 1990-94

The period 1990-94 marks the second crisis of the Brazilian aircraft industry. While global recession caused value added for the global aerospace industry to decline by 30%, Brazil was hit more severely. Sales plummeted by some 75% and exports by 80% from the level of 1990. Figure 4.6 does not only reveal the reduced production of the EMB-120 *Brasilia*, but also shows that there was a gap during which no new aircraft was introduced to the market. This therefore indicates a crisis of the innovation system. [83]

The primary cause of the crisis was a daunting lack of financial resources. The preceding years saw the end of the military dictatorship and a financial and economic crisis in Brazil. The previous practice of financing new product development with government launch support was no longer an option. Financing R&D for a new regional turboprop plane from own resources was beyond the capacity of the heavily indebted Embraer, and collaboration with the Argentinean FAMA turned out to be too costly. By 1994 R&D expenditures of Embraer exceeded 30% of its sales (Figure 4.9). The company had to reduce its workforce to less than half the 1989 levels.

Figure 4.9 R&D Expenditure and R&D intensity of Embraer, 1983-2007 (Million USD at constant = 2000 prices)



Source: own compilation based on Embraer annual reports and Frischtak (1992)

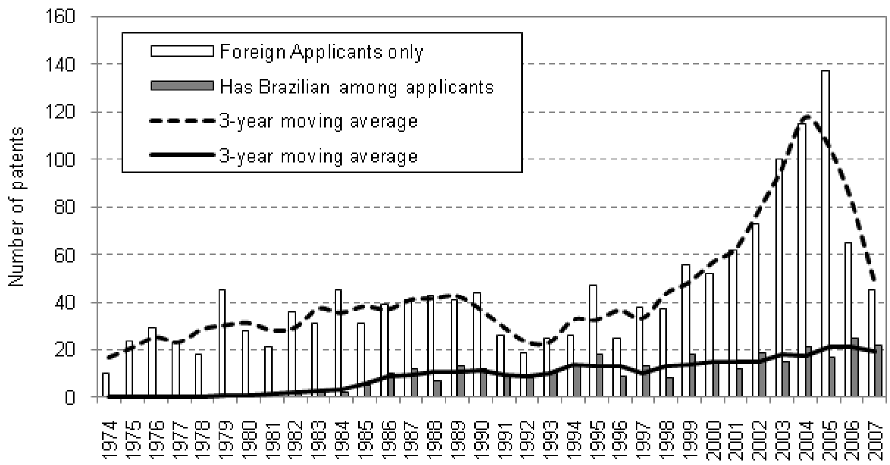
The survival of the production and innovation system was at stake. A more than 40% drop in patenting by foreign companies marks a significant lack of trust in the Brazilian

[83] See Frischtak (1992) for a comprehensive analysis of the crisis.

DOI: 10.14267/phd.2016013

SSI (Figure 4.10). Although patents are not the most appropriate measure of innovativeness in the aerospace industry[84], the trend of foreign companies patenting[85] in Brazil is a crude indicator of technology flows and technological learning in the innovation system. Given a strict intellectual property regime, foreigner's patenting activity reflects their estimation of local technological capabilities. During the 1980s nearly 40 patents a year were added to the stock (Figure 4.10), followed by a sharp, four-year interruption.

Figure 4.10 Number of patents in the field of aerospace granted by year of application (1974-2007)



Source: Brazilian Patent Office via Esp@cenet

By that time, the technological challenges of aircraft manufacturing changed from priorities of fuel efficiency to cost reduction in all operational aspects, noise reduction and capacity increase (Sehra and Whitlow Jr 2004). The global industry had already introduced new ways to cut costs. These included the geographical expansion of supply chains and sharing development costs with component manufacturers, and the development of aircraft families with high commonalities between the different models produced. Embraer still vertically integrated all design and production phases and performed R&D activities in too many different directions (Frischtak 1992). In short, following an external political and macro-economic shock the Brazilian aerospace

[84] Patents are less important as indicators of innovative performance in the aerospace industry as compared to other high-tech industries such as biotech, since innovations are preferably protected by secrecy (Niosi and Zhegu 2005), which is a quite efficient given the high capital barriers.
[85] We distinguished patents in aerospace (classification B64) filed at the Brazilian patent office by the nationality of applicants. The two groups are: all-foreign, where there is no Brazilian applicant, and the rest, where there is at least one Brazilian applicant. Note that change in the trend can also be caused by an overall change in innovative performance of foreign firms.

DOI: 10.14267/phd.2016013

industry lost its competitive edge and the innovation system was not able to help it regain.

4.2.5 A radical change in the Brazilian sectoral innovation system

The solution to overcome the crisis was a change in ownership that fundamentally altered the pattern of interdependencies in the sectoral innovation system. In 1994 Embraer was privatized to a consortium of Brazilian enterprises and pension funds, led by the Bozano Simonsen Group, while the government retained a "golden share" and a seat on the board of governors.[86]

Although the government did not use military procurement for launch support, it continued to fund part of Embraer's R&D activities and exports[87] (through FINEP, the Brazilian Economic and Social Development Bank (BNDES) and Banco do Brasil). At the same time, spin-off enterprises (with former Embraer employees) joined the local supply chain. Privatization resulted in capital injections as well as greater flexibility to sign partnership agreements to jointly develop a family of regional jets. But the most important organizational innovation to regain competitiveness was the creation of a system of risk-sharing partnerships (see Cassiolato *et al.* 2002; Marques 2004; Goldstein 2002a; Figueiredo *et al.* 2008). This was already the common practice of leading aerospace producers in Europe and the US who realized the need to cut costs by focusing on core competences and sharing R&D costs with component suppliers. Adoption of this new form of organization allowed shorter lead times due to parallel manufacturing, but also ensured that Embraer applied the latest technologies, given the fact that many of its partners were suppliers of the leading global producers. Embraer thus changed redefined its core competence as aircraft designer and system assembler. At the same time, this posed new challenges for other companies in the sector, who needed the capital and technology to compete with major foreign parts and components suppliers to win long-term contracts.

The hallmark of the new period is the realization of the ERJ-145 regional jet program. It was already underway from the end of the 1980s, with numerous changes in designs. Interest in the design of a regional jet was already high at the 1989 and 1991 Le Bourget air shows. The project could not have been financed without privatization of

[86] The former founding CEO of Embraer, Silva was instrumental in the privatization of the company. As he noted in an interview (Silva 2009) that the company was not intended to be sold to foreign competitors and in many cases, personal relations helped convince investors.

[87] The PROEX export financing scheme was contested in a WTO trade dispute by Canada, but after the settlement a slightly modified version still remains in place (Goldstein and McGuire 2004).

DOI: 10.14267/phd.2016013

Embraer and without four foreign companies, Gamesa (Spain), ENAer (Chile), Sonaca (Belgium) and C&D Interiors (USA) teaming up as risk sharing partners.[88] The plane completed its first flight in August 1995 and was first delivered to ExpressJet in the US (the regional division of Continental Airlines). The US had been the biggest market for the ERJ-145s. The relatively low price, low operational and maintenance costs combined with the export financing scheme offered by BNDES and Banco do Brasil made the planes especially competitive over Bombardier's CRJ series regional jets. The direct export financing and interest equalization program triggered harsh criticism by Bombardier that escalated to an intergovernmental trade dispute in 1996 between Canada and Brazil at the WTO.[89]

Embraer made use of the family concept and introduced shorter versions of the ERJ-145. The 37-seater ERJ-135 only differed in fuselage length. This latter model also appeared in a business jet configuration as Embraer *Legacy*. A transport model, an airborne early warning model and a remote sensing and a maritime patrol model were also introduced and sold to military operators on three continents. The high degree of communality allowed for reductions in design and certification time, in production costs as well as costs for training flight crew and operations for airlines. The ERJ-145 family has sold with huge success; over a thousand planes have rolled out in little more than a decade.

It did not take Embraer long to start on the development of a family of even larger sized regional jets, the ERJ-170/190s, serving the 70-110 seats range. (Embraer's marketing experts developed the "rule of 70/110", the important commuter market underserved by other producers.) The idea of risk sharing partnerships was at the core of this program as well, with an even higher degree of integration and sophistication of strategic partners. The planes were truly co-designed by the partners, with Embraer taking a 45% stake in the project, and the rest taken by the 16 partners chosen in a competitive selection process. One of the biggest partners was GE, the producer of engines (a package worth around 20% of the plane price). Honeywell (a GE subsidiary by now) was responsible for avionics, Gamesa of Spain for the tail section and rear

[88] Gamesa was responsible for the production of the wings, engine nacelles, fairings of the wing and fuselage junction and the doors of the main landing gear; Sonaca for the production of the luggage, service and main doors on the fuselage, a front and rear section of the fuselage and the two motor pylons; ENAer produced the horizontal stabilizers and rudder controls; C&D Interiors designed and produced the interior of the passenger cabin and luggage compartment. For a visual depiction of division of labor, see Cassiolato *et al*. 2002, Fig.1, p.31).

[89] For a details recount of the "export subsidies saga", see Goldstein and McGuire (2004).

DOI: 10.14267/phd.2016013

fuselage. Liebherr supplied the landing gear and Kawasaki Heavy Industries of Japan was in charge of parts of the wing control surfaces made using composite materials and pylons. Indicating the efficiency with which Embraer engineers and management have “learned” to benefit from risk sharing partners, the project phases have progressed tightly according to schedule. The preliminary studies, partner selection, joint definition and development phases all involved intensive interactions between the partners, facilitated by the use of software allowing entirely digital design and data sharing and utilization of a Virtual Reality Center. These changes not only raised the level of technological precision, but also significantly reduced development time and costs. The 80-seater ERJ-170 first flew in February 2002. After a two-year certification process, the first plane was delivered to LOT Polish Airlines. A slightly stretched version with 88 seats, the ERJ-175 was introduced a year later. Another step forward was the launch of the ERJ-190 program in 2004. The first 110seater ERJ-190 flew in 2004, followed by the 122-seater ERJ-195 a few months later. The American low-cost carrier JetBlue became the launch customer with an order of 100 and option for another 100 planes. The 190/195 planes have a longer redesigned wing and greater engine thrust. With these planes Embraer has directly become a competitor of the larger plane makers Airbus and Boeing, challenging their smallest models (the A318 and the B717 and 737-600s respectively).

Additionally, a fleet of business jets complemented the product list available from Embraer: the *Lineage* jet is an ERJ-190 with redesigned interior, while the *Legacy* 600 is based on the ERJ-145, with increased range and performance. There is a new family under development: the smaller *Legacies* are newly made mid-light jets whereas the *Phenom* 100 and 300 are (very) light jets in production since 2007 and 2008. Table 4.2 provides a historical overview of the aircraft produced by Embraer over 40 years.

Embraer has been expanding its capacity; apart from the original plant (‘Faria Lima’) at the airport of Sao José dos Campos (near CTA/ITA), Embraer opened another site in Eugenio de Melo in 2001, specializing in the development and manufacture of tools and tubing, welded and forged parts, as well as large cabling projects. This site also hosts a school for the Engineer Specialization Program, a postgraduate, in-house interdisciplinary training for future aircraft designers. Another location, opened also in 2001 in the State of Sao Paulo is the newly developed Gaviao Peixoto plant where the planes for the defense and executive markets are assembled. Neiva’s previous facility near the city of Botocatu is the third manufacturing center in the state. The most

DOI: 10.14267/phd.2016013

important aerospace cluster nevertheless remains Sao Jose dos Campos, home to most of Embraer’s suppliers in the lower tiers, many of them spin-off of CTA or Embraer. Apart from the CTA-developed technology commercialized through the establishment of a new company, the streamlining of Embraer’s activities resulted in a number of employees creating their own company as service providers on the second or third tier.

Table 4.2 The main products of Embraer

Type (first flight)	Production		Specification			
	Years	Total nr. produced	Seats (max)	Range (nm)	Maximum Speed (kts)	Altitude (ft)
EMB-110 *Bandeirante* (1968)	1972-90	500	19	1,060	250	22,500
EMB-200 *Ipanema* agro (1970)	1972-	1,000+	1	330	120	11,400
EMB-326 *Xavante* fighter (1957 / Aermacchi)	1971-83	181	2	900	436	41,000
EMB-121 *Xingu* (1976)	1977-87	141	9	1,270	250	26,000
EMB-312 *Tucano* (1980) trainer	1983-98	320	2	1,000	242	30,000
EMB-120 *Brasilia* (1983)	1985-98	330	30	550	300	32,000
AMX (1984) fighter	1989-99	56	2	1,800	626	43,000
ERJ-145 (1995)	1996-		50	1,320	450	37,000
ERJ-135 (1998)	1999-	1,215	37	1,430	450	37,000
ERJ-140 (2000)	2001-		44	1,630	450	37,000
ERJ-170 (2002)	2004-		80	2,100	481	41,000
ERJ-175 (2003)	2005-	682	88	2,000	481	41,000
ERJ-190 (2004)	2005-		114	2,400	481	41,000
ERJ-195 (2004)	2006-		122	2,200	481	41,000
Phenom 100	2008-	178	6	1,200	390	41,000
Phenom 300	2009-		8	1,970	453	45,000

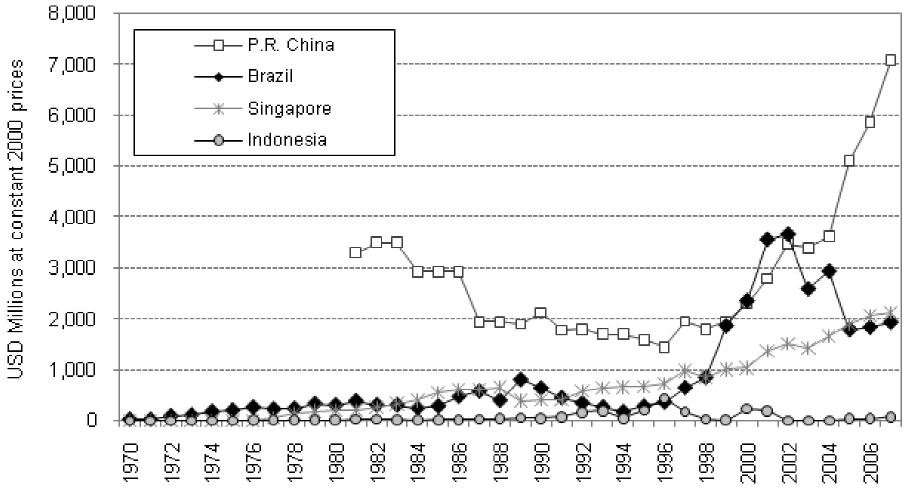
Source: own compilation based on Embraer.com, Frischtak (1992), Ramamurti (1987)
Notes: number produced as of Q3 2010; includes commercial, executive and defense sales.

The results of these institutional changes were remarkable. Between 1994 and 2000 sales rose on the wings of the ERJ-145 regional jet family from less than 200 million to over 2.8 billion US dollars, more than 97% of which came from exports. Value added increased to 2.3 billion USD (Figure 4.11). But while Embraer’s absolute R&D expenditure increased, the R&D/Sales ratio decreased from over 30% to less than 5% (Figure 4.9), even though Embraer was developing a new family of planes. The larger E-170-190 product line can accommodate up to 120 passengers making Embraer a direct competitor of Airbus and Boeing in their smaller product lines. Embraer introduced over a dozen new models of regional and executive jets since the system

DOI: 10.14267/phd.2016013

transition and became third largest manufacturer of jet aircraft worldwide in terms of delivery.

Figure 4.11 Aerospace industry Value Added in Brazil, China and Indonesia, 1970-2007 (Million USD at constant = 2000 prices)



Source: Brazil: IBGE yearbooks, China: CNBS yearbooks, Indonesia: UNIDO yearbooks.
Note: The following industry-specific conversion ratios were applied (updated or backdated to 2000): BRL/USD: 1.09 (see Chapter 4); CNY/USD: 4.6 (Szirmai *et al.* 2005); IDR/USD: 4201 (Stuivenwold and Timmer 2003).

4.2.6 A new transition?

Companies in the Brazilian supply chain benefited from the growth during the late 1990s. However, the share of Brazilian content decreased with the new product line and between 2002 and 2005 value added fell back to 2 billion USD.[90] There are several signs of shortcomings of the SSI that may signal some further changes, albeit less fundamental than those in the 1950-60s or in 1994.

The Brazilian aerospace industry recovered from the post-9/11 demand shock relatively rapidly. However, the crisis of 2008-09 showed greater vulnerability of an industry dependent on regional and executive jets. The relatively outdated technological capabilities, the lack of sufficient credit lines and venture capital make it difficult for local SMEs to become competitive and join global supply chains as risk sharing partners (ABDI 2009). To boost the competitiveness of local SMEs is a major concern for the government. There is a growing consensus about the need to modernize the education and training system, to support innovativeness through new aircraft

[90] For a discussion of trends in value added and labour productivity, see Chapter 4.

DOI: 10.14267/phd.2016013

development and procurement policies or offset agreements targeting the supplier chain to create a globally competitive center of excellence in aerospace.[91] As a first response, in 2009 the government officially commissioned Embraer to development a military transport and tanker aircraft (the K/C-390).

In the meantime, the global competitive landscape is changing and new planes need to be even more fuel efficient to reduce operations costs and greenhouse gas emissions. The latest large civilian aircraft designs use composite materials at an unprecedented scale, in which Embraer is lagging behind.[92] The cost share of avionics in a new aircraft has reached unprecedented heights. Brazilian companies in these two rapidly growing technology domains have no frontier capabilities to offer for foreign system assemblers. In the regional aircraft market new players (including Comac in China, the Russian Sukhoi and Mitsubishi in Japan) have made significant investments to break the Bombardier-Embraer duopoly. Thus the competitiveness challenge might call for a new innovation system transition.

We have yet to see major institutional changes in the Brazilian innovation system. What changed after the crisis was the launch of the military transport project which indicates a replacement of commercial investments with (potentially in the short term) public investments (to be phased out by export to the military market in the long run).

4.2.7 Interrupted innovation in the Brazilian aerospace industry

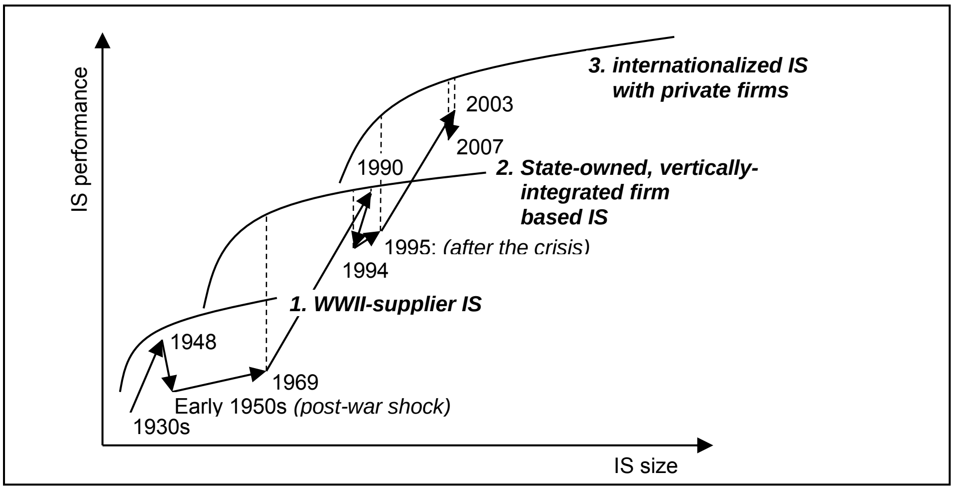
The overview of the history of the industry helped us identify historical turning points of interruption, crisis and transition. Such turning points (often not single moments but periods lasting several years) are the post-WWII crisis in the early 1950s, the creation of Embraer in 1969, the interruption following the financial crisis in 1989-90 and the transition connected to the privatization of Embraer in 1994. Using the interrupted innovation framework developed in chapter 5, the changes in innovation system size and performance are charted in Figure 4.12.

[91] Clearly indicated by recent detailed, comprehensive studies, see ABDI (2009) and Montoro and Migon (2009).

[92] When deciding for the use of composite materials, there is of course a tradeoff between production and spare-parts costs and operating costs.

DOI: 10.14267/phd.2016013

Figure 4.12 The interrupted trajectory of the development of the Brazilian aerospace industry (1930s-2007)



(Author's compilation)

1. From the 1950s until 1969, the growth in size of the system exceeded its performance growth, although both were positive. Size expanded due to technology inputs from foreign designers and the work of CTA and new skilled labor inputs from ITA. The performance increased owing to a few new designs, but as production was limited to a few small planes, we assume that less process innovation took place.
2. A transition to another innovation system was finalized in 1969. A state-owned company was created that specialized in commercial and military aircraft development, production and marketing. Embraer became the single most important corporate actor in the system receiving most inputs into innovation.
3. From 1969 and 1990, both the size and the performance of the system increased hugely. (This trend is not linear. The figures presented earlier showed that R&D, employees, new products, patents, and sales fluctuated from year to year.) Based on the relatively high global market share of two of Embraer's commuter aircraft, we conclude that the performance of the innovation system was close to its frontier. [93]
4. The interruption between 1990 and 1994 is evidenced by the decrease in system size (due to decrease of R&D expenditures, employment and increase of debts) and performance (lack of new patents, new product sales or new process

[93] See Marques 2004 for more details on the system.

DOI: 10.14267/phd.2016013

innovation). It became clear to the major actors that a return to the old system of innovation would be insufficient to sustain competitive advantage.

5. After 1994, both the size and the performance of the innovation system grew at an unprecedented rate, made possible by a transition to a new system based on strategic alliances in R&D as well as in production, which allowed the input of frontier technologies from the best global suppliers. The increase in size and performance was once again not linear (with a significant break in 2002-3), but overwhelmingly the trends were positive.
6. The 2003 drop in value added indicates a new crisis in the industry. This primarily concerns companies other than Embraer (which still increased sales and export until 2007). However, Embraer’s R&D intensity remained at a low level. Until now, no fundamental institutional changes have occurred.

DOI: 10.14267/phd.2016013

4.3 CHINA: Slowly transforming, parallel systems

4.3.1 Introduction: from military to civilian innovations

After entering the aircraft manufacturing industry in the 1950s,[94] China has become a producer and – to a lesser extent – exporter of fighter jets (Figure 17), bombers and light transport aircraft during the Cold War (CIA 1972, Allen *et al*, 1995, Frankenstein and Gill, 1996). Since the 1990s firms of the Chinese aeronautical conglomerates have joined the global supply chains as manufacturer of commercial aircraft parts and components for western producers, including Airbus and Boeing (KPMG, 2004). In the last decade foreign manufactures (Embraer, Airbus) brought final assembly work to China and the Chinese company (Comac) designed and produced a prototype of a regional jet (Goldstein 2006). This marks the end of a slow transition that started in the late 1980s and established a dualist structure by today. The opening up of the military-industry complex (MIC) and the expansion of civilian production brought along fundamental institutional and organizational changes in an industry that at some point during this process employed over half a million people.

4.3.2 The Sectoral Innovation System in the emergent phase: an inward-looking innovation system

4.3.2.1 Legacies of the Military-Industry Complex (MIC)

China at its peak in the late 1970s was estimated to produce over 400 aircraft a year (see Figure 4.13). But despite the large quantities, Chinese military aircraft technology maintained at least a generation's lag compared to the benchmark Soviet frontier technology, due to difficulties in acquiring the required technologies (Frankenstein and Gill 1996). Chinese design and production plants had to substitute the previously available Soviet technology through reverse-engineering after the 1961 Sino-Soviet split. The military-industry complex, created but also hindered by national security concerns, has never emerged as a fully functional sectoral innovation system. Unlike in Brazil where the aerospace industry concentrated around the single Sao Jose dos Campos cluster, at least a dozen of centers were created all over China involved with aeronautical R&D, maintenance and production work. The most important production facilities were located in Shenyang and Harbin in the northeast, Chengdu in the

[94] Due to lack of space, we do not discuss here the emergence of the Chinese aerospace industry and innovation system.

DOI: 10.14267/phd.2016013

southwest, as well as around Shanghai, Xian and Taiyuan. Aircraft factories oversaw hundreds of enterprises and also produced non-aviation products to utilize idle capacities. Productivity was not a major concern for the division of labor between these factories and multiplication of tasks was common due to lack of linkages between parallel projects. The organization of the industry showed a ‘satellite pattern’, decisions were made in Beijing and there was little interaction among the facilities.

Supervision and coordination of R&D and production activities was the responsibility of the Commission on Science, Technology and Industry for National Defence (COSTIND), a body reporting both to the PLA as well as to the State Council. The only source of finance was the government (the Military or State Council), and the expenditures on various projects remained concealed. The production cycle of military aircraft is clearly influenced by political events (Figure 4.13).

While research and engineer training was located around the production facilities, university level education in disciplines related to aerospace were offered in Beijing (BUAA) and Nanjing (NUAA).

Over these inward-looking years Chinese plants developed significant technological capabilities to introduce mostly “new-to-the-country” innovations based on reverse-engineering and local development efforts. The MiG-19 served as the base of two planes: the Shenyang J-6 fighter and the Nanchang Q-5 ground attack aircraft. The J-6 shows little difference from the Mig-19s and was already introduced before the Sino-Soviet split. This supersonic fighter jet was originally designed with a rather short operational life and Mikoyan administration in the Soviet Union replaced the Soviet version very soon. But in China the older version was the most advanced model fully available at the time of the split and this model was produced in great numbers in Shenyang[95]. A redesigned, ground-attack version of the MiG-19 included modifications such as a longer fuselage, larger wings, an internal weapons bay able to accommodate even nuclear weapons; air intakes put to the sides but fitted with the same “Liming Wopen” turbojet engine (a copy of the Soviet Tumansky). This model could reach higher altitudes, but lower speeds than the MiG-19. The prototype was already completed in 1960 in Shenyang. However, the project was moved to Nanchang in 1963 after loss of political support. It first flew in 1965 and series production started in 1969.

[95] About 3000 planes are believed to have been built between 1958 and 1981.

DOI: 10.14267/phd.2016013

About a thousand planes were built and a few were exported (as A-5s) to Pakistan, Bangladesh, Myanmar and North Korea.

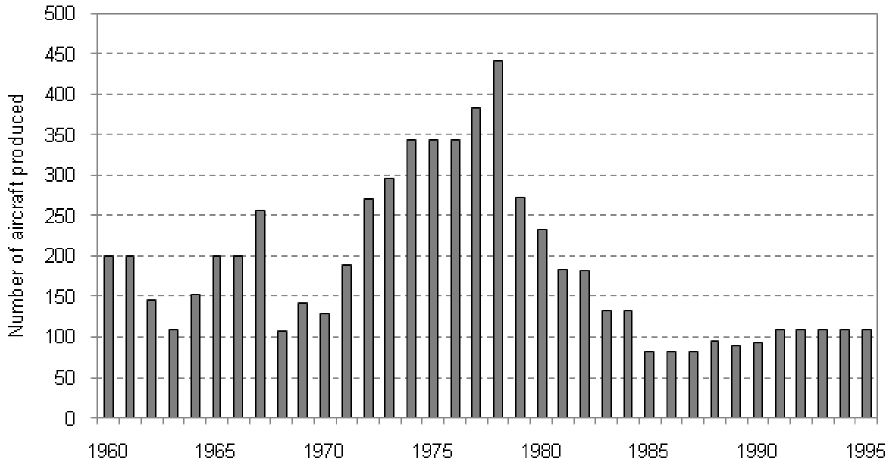
China produced may fighter jets based on the Soviet MiG-21. Initially, the technology was intended to be transferred to China, but the political split affected this project as well. However, after two years, a new deal was signed in 1962. Some kits and parts were indeed delivered, but some of the documentation was missing and Chinese engineers had to fill in the gaps with a number of technical solutions until the plane could commence its first flight in 1966 (at which time the Cultural Revolution caused further delays.) Series production started only in 1980; more than 2,400 planes were produced over 25 years. Despite its older technology (the Soviet MiG-21 production ended in 1985), the J-7 (or F-7, according to its export name), became a rather successful model, owing much to the successful design of the original MiG-21 and the relatively lower price China asked. The J-6 and J-7s were China’s most successful export models. It is estimated that around 680 J-6s and 520 J-7s were sold, bartered or donated to other countries (including the trainer version). Figure 4.14 indicates the annual number of planes exported.

The development and the modifications of the Shenyang J-8 fighter characterize the functioning of a defense-oriented innovation system. The original model largely resembled the MiG-21 based J-7, except for the larger delta wings, and additional engine and a very simple radar, making it a more capable interceptor at higher altitudes and faster speeds. It first flew in 1969, but it didn’t enter into serial production before 1979 due to the Cultural Revolution. But the plane fell short of the expectations of the PLA Air Force (PLAAF) which was looking for all-weather, high-altitude, and beyond-visual-range interception capabilities that could counter foreign spy-planes. Even with incremental improvements in armament and avionics during the 1980s, the plane remained an obsolete model. It is estimated that hardly more than 50 of these J-8I planes were produced. A radical modification of the original design involved replacing the nose air intake for the engines with side air intake, which allowed the solid nose to host a more advanced radar system. The resulting J-8 II showed little resemblance to the original J-8, except for the tail section and the delta wings. The new nose design was apparently largely inspired by the Soviet MiG-23 and Su-15 fighters. This model accomplished its maiden flight in 1984 and was developed parallel with the J-8I upgrades. The original 40 km radar range of the J-8IIs was replaced by 70 km radar in a 1989 batch, still not capable of locating beyond visual range. Maneuverability was also

DOI: 10.14267/phd.2016013

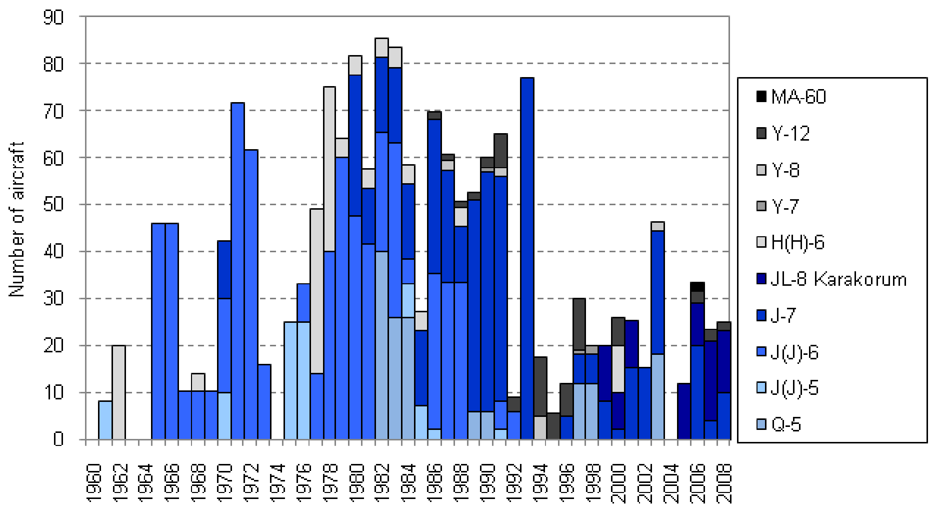
slightly improved and so were avionics. But incremental innovations in its modules were relatively slow during the 1980s and 1990s as cooperation with the US was terminated after the Tiananmen Square incidents. By the time upgrades were made with Israeli and Russian technology, the newer plane J-11 fighter was already available. Nevertheless, an upgraded version of the plane was displayed even as recently as in 2006. It is estimated that 300-350 of these planes have been produced.

Figure 4.13 Estimated Chinese Jet Fighter Production, 1960–1995



Source: Allen *et al.* (1995 Fig.17, p.162)
Notes: This figure clearly indicates the influence of major political events: the Sino-Soviet split of 1961, the Cultural Revolution during the late 1960s and the reforms of Deng Xiaoping following 1978.

Figure 4.14 Military aircraft export from China, 1960-2008



Source: SIPRI

DOI: 10.14267/phd.2016013

Notes: Q refers to ground attack class, J refers to fighters; H refers to bombers and Y refers to transport aircraft. Double letters indicate trainer versions.

4.3.2.2 The origins of commercial production

Even before the more fundamental institutional changes of the 1990s, there were several attempts to diversify into the production of commercial aircraft. The Y-10 project of the 1970s proved that Chinese engineers were capable of designing prototypes of a large civil aircraft that were able to fly.[96] However, the project never reached the phase of series production and was cancelled in 1983. It did not turn out to be commercially viable and the Aviation Administration of China preferred to import more modern planes.[97]

The MD-80 assembly project was the first bold sign of opening up the industry to western technology and commercial production. In 1985 China signed a license agreement with McDonnell Douglas (MD) to assemble the MD-80-series medium range jets in Shanghai. The airplanes were assembled from kits with some components fabricated in China. MD provided technical data, training, and on-site assistance. 35 planes were produced between 1985 and 1994, mostly for the local market (30 were sold to China Northern and China Eastern and 5 were exported to the US). The Shanghai-produced planes were however repeatedly experiencing technical failures and clocked only a modest amount of flying hours. A renewed contract for 20 Chinese MD-90s *Trunkliner* with an indigenously produced share of 80% resulted in only 2 planes delivered for China Northern in 2000. Despite low productivity[98] and quality problems, the technology acquired through this endeavor gave a major push to the industry, and also found its way to the first indigenous design, the ARJ-21 regional jet.

Quality problems hampered the success of a smaller-scale project, the multiuse turboprop military / civilian transport plane based on Soviet Antonov design, the Xian Y-7, later the MA-60. These projects already included collaboration with Western partners. But these Chinese made planes had limited success on the export markets since

[96] Although the Y-10 shows a high degree of similarity to the Boeing B-707, Chen (2009) argues that some of its features even outperformed the B-707. Thus it was innovation, not merely imitation.

[97] It was based on 1950s technology and Boeing stopped producing the 707 in 1979 due to its high fuel consumption. Political reasons might also have played a part: possible pressure from the US as well as the end of influence of the ‘Gang of Four’ who were behind the project.

[98] During the twenty years period of its production, the US produced over 1000 of these planes making it the third most successful jets in history, China only assembled 35, most of which were very soon grounded.

DOI: 10.14267/phd.2016013

western administrations did not certify the planes due to quality concerns. Most of them were eventually grounded for safety reasons or lack of spare parts.

4.3.2.3 Main features of the innovation system[99] before the changes of the 1990s

The PLA Air Force (PLAAF), established in 1949 has accounted for a large share of the Chinese defense budget and was a power center from time to time even competing with the State Council. It supervised much of the aeronautics, astronautics and pilot education. The Air Force Command College, Air Force Engineering University, Air Force Aviation University, Air Force Radar College, Air Force College at Guilin, Air Force College at Xuzhou, Air Force School for Noncommissioned Officers at Dalian and seven flying colleges were under its command. Defense budget was as high as from 4.6% of the GDP in 1978 but declined to 1.7% in one decade[100]. After 1978, the new strategy subordinated defense development to be in the service of the country's overall economic development; allowing commercial interests slowly to gain more solid ground from the mid 1980s.

Self-reliance was the most primary goal underlying innovative activities in Communist China before the 1990s, for considerations of national defense. This did not preclude cross-border technology flows and even import of components such as jet engines for Chinese-made fighter jets, or the use of reverse-engineering of imported aircraft (in order not to reinvent the wheel). However, channels were not established for intensive knowledge exchange and new aircraft development was a rather isolated activity, resulting in innovations being at least a generation behind the global frontier. Secrecy prevailed and hampered interactions even between various regional aerospace clusters. A division of labor based on the purpose of aircraft[101] resulted in duplications of tasks and lack of use of economies of scope – again, for strategic reasons. Financing of innovative and productive activities by the state council or the PLA was not transparent.

---

[99] The pragmatic approach of Radosevic (1997) to see socialist techno-economic networks as innovation systems is applicable in the Chinese case as well, since knowledge creation and new product design was an explicit aim, even if the incentives and a number of institutions differed profoundly from a capitalist system.

[100] China's National Defense in 2008 < http://news.xinhuanet.com/english/2009-01/20/content_10688124.htm> (Retreived: March 2009)

[101] For example, fighter aircraft was produced in Shenyang, Chengdu, Guiyang and Nanchang; light and medium transport aircraft in Harbin and Xian; helicopters in Harbin and Jingdezhen; bombers in Xian. (Medeiros 2005) (And this list is not complete).

DOI: 10.14267/phd.2016013

4.3.3 The crisis in the inward-looking innovation system

By the early 1990s, the mismatch between the institutions of the inward-looking innovation system and the competitive landscape became unsustainable. The Chinese aircraft manufacturing factories were producing a wide range of non-aviation products for which demand was higher. Locally designed planes were not economical and not safe to operate. Chinese fighters and transport planes would not sell on foreign markets, not even in the most price-sensitive Third World countries. Despite the remarkable efforts of producing and upgrading planes, the industry was increasing the gap compared to the technological leaders. The innovation system which was based on reverse-engineering and local improvements became increasingly inappropriate in a new era of opening trade relations.

Yet producers were lacking state-of-the art knowledge, skills and financial capabilities to join the newly emerging global supply chains. At the same time, the demand for commercial aircraft in China grew sharply which could only be met realistically with Western imports in medium term. China had no options but to rethink its aircraft industry development strategy.

4.3.4 A radical change in the Chinese sectoral innovation system in the 1990s

The transition in the aerospace industry and innovation system was part of broader market reforms in China. The iterative but fundamental institutional changes in the national innovation system were correctly described as ‘adaptive learning’ (Gu and Lundvall, 2006). Certain heavy industries (including automobile) were consolidated in a shorter time, but aerospace remains a slow mover, given its sheer size (it employed nearly 600,000 workers in 1995) and the reluctance of chief financing and regulating bodies of the military to change their mindset. Following a 1991 order of the more demand-conscious government, the PLA was to shift 80% of defense manufacturing projects to commercial products (Allen et al, 1995), in order to tackle financial difficulties. The successful transition of other industries certainly serves as an example for aerospace.

Demand for air travel spurred by growth of the economy has been a major driving factor of industrial change. Both international and domestic air traffic have increased

DOI: 10.14267/phd.2016013

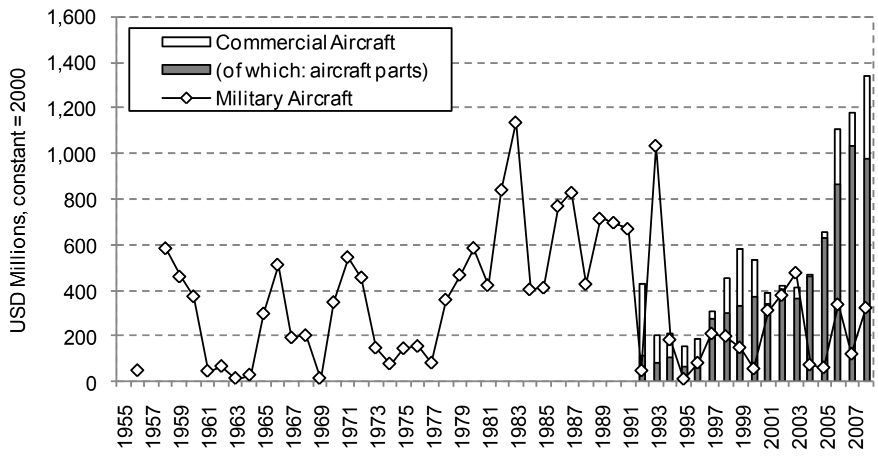
dramatically since the late 1980s.[102] However, the Chinese air transport market remains tightly regulated and aircraft load factors and flying hours remain suboptimal, airport capacities underused (Goldstein, 2006).

4.3.5 Empirical evidence of interruption and transition

Value added: Aerospace value added exceeded 3.5 billion dollars in 1983. Following a sudden drop in fighter aircraft production, it fell to 1.9 billion by 1987 and continued to decrease to a low of 1.4 billion USD in 1996. After a turnaround, with an average growth of over 16%, the value added of Chinese aerospace industry exceeded the levels of the early 1980s by 2005. In 2010, it reached a historic 11.5 billion USD.

Export structure: The composition of the industry's exports shows a striking change. Between 1970 and 90, China exported an annual average of 0.5 billion dollars worth of (mostly locally manufactured) military planes. During the following two decades this amount was halved. At the same time commercial aircraft parts and components exports grew from some 100 million dollars at the beginning of the 1990s to over 1.8 billion USD by 2010. Nevertheless, China continues to import almost all of its commercial aircraft (Figure 4.15)[103];

Figure 4.15 Export of Chinese Military and Commercial Aircraft, 1955-2008 (USD Millions, Constant = 2000)



Source: SIPRI; UN COMTRADE (data only available from 1992)

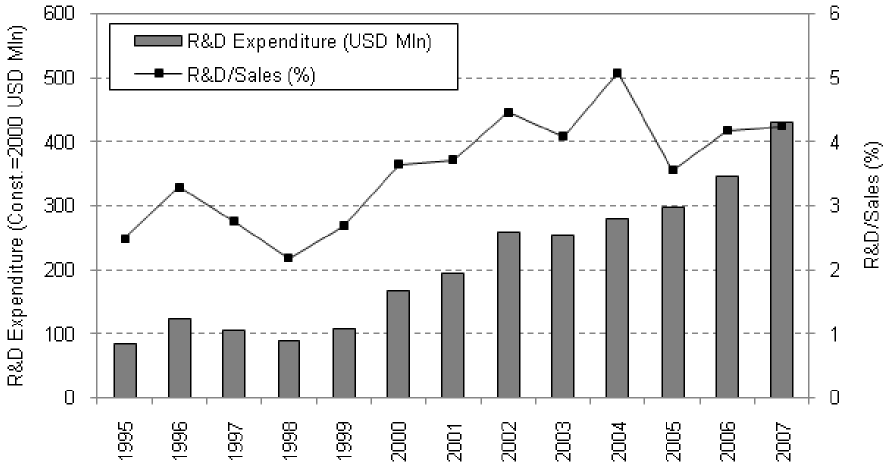
[102] Passenger air traffic doubled between 1985 and 1990 to 23 billion passenger kilometer. This value nearly tripled by 1995 to 68 billion, still merely 10% of US air traffic. It further tripled to 200 billion by 2005 and latest figures show 290 billion by 2008 (CNBS).

[103] Import (of mostly complete aircraft) grew from 1.6 billion in 1992 to over 8.4 billion USD in 2006.

DOI: 10.14267/phd.2016013

R&D expenditure: Data on aerospace R&D is available from 1995. From an annual average of 100 million USD until 1999[104] the launch of major national aircraft development projects led by 2007 to an increased R&D expenditure of 430 million USD[105]. Similarly, there is also a significant increase in new product development expenditures starting from 2002 (China National Bureau of Statistics). Comparing industrial R&D expenditure to aggregate sales shows relatively little fluctuation and an increasing share of R&D (Figure 4.16).[106] Most recent data from the Chinese Bureau of Statistical shows that R&D intensity increased significantly from 2010 to 2011, reaching 7.7% of sales.

Figure 4.16 R&D Expenditure and R&D per Sales in Chinese Aerospace Industry, 1995-2007 (USD Millions, Constant = 2000)



Source: China National Bureau of Statistics.
Note: Annual Average exchange rate in 2000 of 8.28 CNY/USD was applied (IMF).

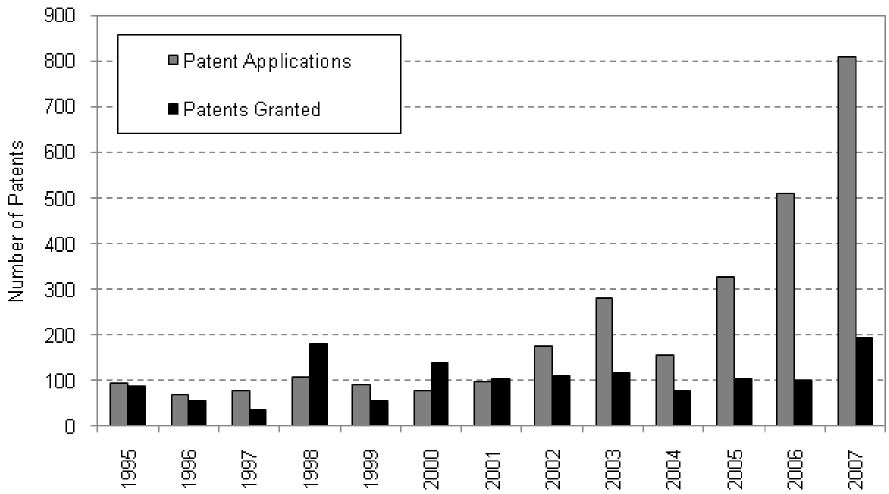
Patent applications: Although we have repeatedly questioned the appropriateness of patent statistics as an indicator of aerospace innovation, the trend in patent levels may nevertheless provide some information on radical system changes. Indeed, there is a clear trend break in the patenting activity of Chinese large and medium sized enterprises in 2002 (Figure 4.17). From an average level of 90 applications a year which was typical for the late 1990s, the number of applications started to increase and reached 810

[104] For a comparison, during the same period Embraer alone spent the same amount on R&D.
[105] In comparison, in 2000 the US spent a total of 10.3 billion USD on aerospace R&D, and 14 billion in 2006.
[106] At the same time the R&D staff levels decreased. In terms of full time equivalent, the level of R&D personnel in the sector decreased from a level of 30,800 in 2000 to 27,200 man years by 2007.

DOI: 10.14267/phd.2016013

in 2007. The number of patents granted only started to show significant changes from 2007 onwards.[107]

Figure 4.17 Patent statistics of aerospace enterprises



Source: China National Bureau of Statistics, various yearbooks
Note: Data refers to patenting activity of large and medium sized enterprises defined by main activity

4.3.6 The new Chinese aerospace innovation system

4.3.6.1 Organizational restructuring of production

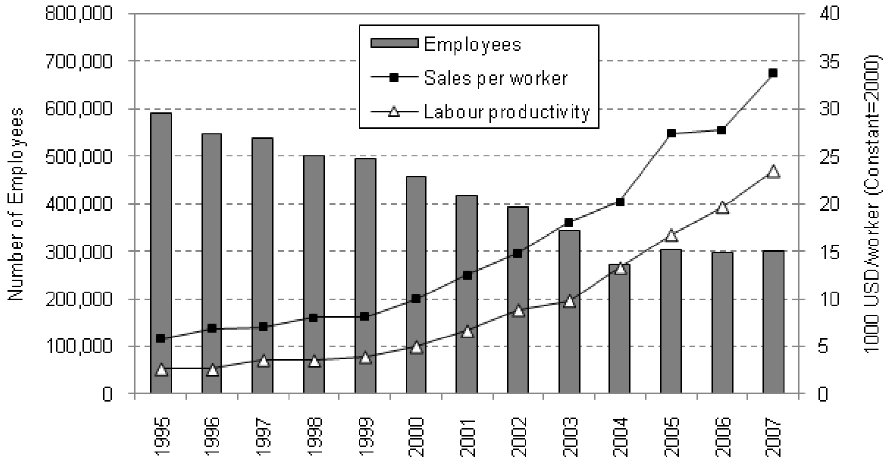
These developments in the accumulation of technological capabilities were set against a dynamically changing organizational structure. The first sign of opening up the military-industry complex was the creation of Aviation Industries of China (AVIC) conglomerate in 1993 (controlling all the aeronautic research and production facilities) and China Aerospace Corporation (CASC, in charge of the astronautic programs and missile system development and production). In July 1999, AVIC was split up into two enterprises with the goal to break up the monopoly and to foster competitiveness. AVIC I's business focus was manufacturing commercial, interceptor, interceptor-bomber, tanker, transporter, trainer, and reconnaissance aircraft, while AVIC II focused on helicopter, transporter, trainer and general aviation aircraft. AVIC I was launched with 104 enterprises, including 31 of the AVIC's original 34 research centers, and 281,000 employees. It streamlined its structure by 2006 and had 230,000 employees and increased sales revenues. AVIC II was launched with 54 large and medium sized

[107] The lengthiness of the patenting process can well explain this lag. A further growth in 2008 is confirmed by the latest statistics on the sector, although not shown in the figure.

DOI: 10.14267/phd.2016013

enterprises, 3 research institutes, 22 other subsidiaries, and 210,000 employees. Either intentionally or not, one significant result of the restructuring was increased labor productivity through reductions in the number of employees. Total employment in the sector shrunk in a decade from some 600,000 in 1995 to a stable 300,000 in 2005. Labor productivity increased from 5,000 to 24,000 US dollars per worker between 2000 and 2007. These are evident signs of consolidation in the industry, even if this might not remain the final setup.[108]

Figure 4.18 Employment and Labour Productivity Growth in the Chinese Aerospace Industry, 1995-2007
(Thousand USD at constant = 2000 prices)



Source: Chinese National Bureau of Statistics, various yearbooks
Note: for value added and labor productivity please refer to Chapter 3.

In the complex, cascading structure of subordinate companies, many of the competences were doubled but the final products were more complementary to each other than competitive with each other, contrary to the initial intention (Nolan and Zhang 2002). This was partly the reason why the two sections remerged from 2009 into AVIC, but only after a significant overall reduction in employment by as much as 50%. The lack of transparency in the corporate structure has from time to time slowed down decision making processes, but has also allowed experimentations with new corporate forms, especially when it came to joint ventures with Western companies or subsidiaries created with a mission of commercialization of results.

[108] There is no information how much of the value added and employment is actually associated with aerospace activities. In 2005 Medeiros estimated that non-aviation business made up as much as 80% of AVIC's turnover (Medeiros, 2005). Nolan and Zhang reported earlier that automobiles, components and motorcycles alone accounted for 62% of AVIC's revenue in 1997.

DOI: 10.14267/phd.2016013

4.3.6.2 Foreign aircraft manufacturers in China

While importing most of the aircraft from Boeing and Airbus, China pushed for offset agreements to simultaneously support the technological upgrading of the industry. At first this meant less technology-, more labor-intensive parts (hardware) manufacturing at dozens of locations across the country.[109] Production quality increased substantially as a result of these deals since Chinese suppliers had to deliver according to the same strict standards that other producers faced in the Western countries. The initial political necessity to produce in China soon became an economic advantage for western manufacturers as they reaped the benefits of lower labor costs (notwithstanding the initial learning costs). However, the Chinese contribution remained at the lower tiers of the earlier discussed, newly established global industrial structure. A first risk sharing partnership venture was only signed by a Harbin-based consortium and Airbus for the A-350 XWB project in 2009.

The first foreign manufacturer to commence final assembly of jets in China was Embraer. The Harbin Embraer joint venture[110] of 2003 allowed the Brazilian company to deliver ERJ-145 regional jets for the Chinese market by avoiding import taxes while the acquisition of certain parts manufacturing and systems assembly activities was a major technological boost for the Harbin plant. The results of the venture were mixed: by the end of 2009 only 33 of the original order of 50 jets were delivered[111] although the company had a capacity to produce 24 a year and was expecting new orders. The last of the ERJ-145 is expected to be produced in 2011 and Embraer is now awaiting a government decision to approve a shift to ERJ-190 production. Otherwise it plans to close down the plant.[112] The Chinese government is hesitant since the ERJ-190 would be a direct competitor of the locally developed ARJ-21 (Asian Regional Jet for the 21st Century), due to enter series production in the same time horizon.

---

[109] See KPMG (2004) or Boeing (2008).

[110] The joint venture is special since it allowed a 51% majority ownership for a foreign company. For more details on the 50 million USD deal, see Goldstein (2006).

[111] "Harbin-Embraer's fate rests with China talks" *AinOnline*, 28 Jan 2010 (http://www.ainonline.com/news/single-news-page/article/harbin-embraers-fate-rests-with-china-talks-23599/)

[112] "Chinese govt to decide on future for Harbin Embraer: Curado" *Air Transport Intelligence News* 25 May 2010.

DOI: 10.14267/phd.2016013

Airbus also established a joint venture for final assembly in China.[113] Operations commenced in 2008 at the Tianjin final assembly line (FAL), a replica of Airbus' Hamburg plant. The first A320 was delivered mid 2009. At the moment, production capacity is four aircraft per month. Airbus initially assembled aircraft from kits delivered from Europe, gradually changing to locally made parts.[114] The total investment in the Tianjin FAL amounted to 1.47 billion USD[115]. While Boeing was not ready to take the risk of going to China, Airbus expects that the long term benefits of market access exceed the initial investments.[116]

4.3.6.3 'Indigenous' aircraft development

Chinese ambitions to diversify into commercial aircraft development have increased in the 1990s. There seemed to be an agreement that the first step would be to gain access to advanced foreign technology, but there appeared to be little agreement on how to proceed. Although Chinese airlines showed the largest demand for aircraft with larger seating capacity, regional turboprops and jets were seen as a stepping stone for domestic producers and also as a means to provide access to remote cities with less traffic. The MD-90 *Trunkliner* project fitted in this strategy but failed due to quality deficiencies. Another project of the 1990s that failed to realize was the '*Asian Express*'.

Originally a Chinese – South Korean joint venture from 1994, the *Asian Express* was supposed to be a regional jet in the 80-140 seat range. Following disagreements on the final assembly location and the share of the two countries' stake in the project, the South Korean consortium withdrew from the collaboration in June 1996. AVIC of China then approached Singapore Technologies Aerospace and three European producers, Aerospatiale, Alenia and British Aerospace. Three partners, AVIC (with 46% stake) Airbus Industrie Asia (39% stake) and ST Aerospace (15%) agreed to share the expected 1.7-2 billion USD cost of the project. The sides agreed to develop two models in the 95-125 seat range, the AE-316/7[117]. However, the partners did not share

---

[113] Airbus owns 51% share while the rest is divided by a consortium of AVIC and Tianjin Free Trade Zone.

[114] Avoiding double shipment by directly using components i.e. wing boxes produced by Xian Aircraft Industry Group.

[115] "Airbus delivers first China-made jet, underlining its Asian thrust", *Agence France Presse*, 23 June 2009.

[116] Production is cheaper in China mainly because of (some) reduction in import taxes and duties. The lower labour costs in China are however not necessarily realized in the short run given the high training costs for local labor force and the cost of expatriates (125 of the 500 employees). ("Airbus' China Gamble" *Flight International* 28 October 2008)

[117] The name indicates that the plane was targeted to be a "little sister" of the Airbus A-320 family

DOI: 10.14267/phd.2016013

the same dedication to realize the project. The Chinese industry was in a turmoil and expected to be shaken up, the future of AVIC and the trading company CATIC (China National Aero-Technology Import and Export Corporation) was uncertain. Although China was supposed to get the largest share, Xian and Shanghai were contending for production locations. Airbus officially communicated that the AE-31X was its preferred choice for the 100-seat range, it was already developing and collecting orders for the smallest member of the A-320 family, the "A-319M5".[118] Airbus was also hesitant to share technology with and shift production to China. Technology transfer seemed unavoidable since market surveys showed that airlines expected a high degree of commonality between the new plane and the A-320 family. At the same time, competition was increasing in the 100 seat segment as the aging DC-9s were requiring a replacement and Boeing was one step ahead with the B-717-200 readily available. In the end, the *Asian Express* project was cancelled in 1998, officially explained with financial reasons.[119] It is rather interesting that although European producers were in desperate need to find a solution to save their regional aircraft projects, they eventually did not collaborate with China. The 1990s witnessed European plane makers such as BAe, Daimler, Fokker and ATR gradually losing competitiveness (among others to regional jets of Embraer and Bombardier). Producing in China would have, in the long run, reduced production cost, even if short term investments and training costs were high. The many explanations for the lack of trust on the European side include the existence of an arms embargo following the Tiananmen-square, concerns for national security concerns when sharing multi-purpose technology and concerns for job migration.

The 11th Five-Year Plan for 2006-2010 included the completion of the ARJ-21 regional jet project and the launch of a large aircraft development project for civil and military use, supposed to fly by 2015.[120] Although indigenous in name, both projects utilize global technological and investment capacities, following the risk sharing partnership practice of Western aircraft producers. The ARJ-21 project that started in 2002 still reflects many of its local technological origins. Coordinated by a government-led commercial aircraft company (ACAC, later COMAC)[121], the four plants involved

[118] The code stands for A-319 minus 5 fuselage frames, eventually it became known as the A-318.
[119] "Timeout in Asia" *Flight Int'l*, 5 Nov 1997; "Cut and Thrust" *Flight Int'l, 9 Jun 1999.*
[120] "Official identifies eight goals for China's aviation, aerospace industry", *BBC Monitoring Asia Pacific*, 9 Nov 2006
[121] ACAC, or 'AVIC-I Commercial Aircraft Company' was a consortium of four main companies under the AVIC I conglomerate, designated to oversee the development, certification and marketing of

DOI: 10.14267/phd.2016013

(Shanghai, Xian, Chengdu and Shenyang) were the same as the ones in the MD-90 *Trunkliner* project. It is hard not to notice the resemblance of certain sections of the plane[122]. The largest share of development costs of the first regional jet project, the ARJ-21 were provided by the public aerospace R&D supporter COSTIND, but leading transnational companies participate in financing the development.[123] The US Federal Aviation Authority (FAA) has been involved in the development process in order to facilitate certification. The fact that the “First Chinese Made Plane” will not bear “Made in China” tags only is an indicator of the maturity of Chinese design and organizational capabilities. The arrangement of acquiring technology and finance through risk sharing partnerships is similar to the strategy Embraer chose in the mid 1990s, but for the arrangement to work efficiently, private ownership of Embraer was crucial.

The ARJ-21 made its maiden flight at the end of 2008 and four prototypes are currently undergoing tests. Series production and the establishment of a distribution network has not even begun when the government announced the plans to develop a large civil aircraft[124] in the 168-190 seats category. The COMAC C-919[125] would be a direct competitor of the smaller Boeing and Airbus jets (B-737 and A-320 family), bringing new turbulence to a consolidated duopolistic market. China has yet to gain experience in setting foot on the international aircraft market, which involves winning the trust of passengers and airlines, establishing the maintenance, repair and overhaul network, and efficient supply chain management. This step is crucial to recover the huge sunk costs of development, and still requires vast investments domestically and overseas.

---

commercial aircraft. In 2009 the company became part of COMAC, the ‘Commercial Aircraft Corporation of China Ltd’ established in 2008.

[122] Highly similar parts include the nose, produced by Chengdu, the fuselage by Xian, the tail section by Shenyang or the horizontal stabilizers by Shanghai (Andersen 2008). The aircraft was thus aptly named *Xiangfeng* (flying phoenix), as it was revived from the ashes of the failed MD-90 *Trunkliner*.

[123] Foreign partners include Antonov (wing design and testing), General Electric (regional jet engine development), Rockwell Collins (avionics), Hamilton Sundstrand (electric system and auxiliary power unit and fire protection system), Eaton (control panel), Liebherr (landing gear). Boeing has been providing engineering consultancy and cockpit design assistance.

[124] ‘Large civil aircraft’ is a more appropriate term for this narrow-body jet than the often used ‘jumbo’, which normally refers to Boeing B-747s with a seating capacity in the range of 500.

[125] The list of collaborating partners has not been finalized yet; currently Hongdu (Nanchang), Xian, Shenyang and Chengdu Corporations are the Chinese companies involved (“China’s Comac brings more suppliers in, *Flight International*, 24 Sept 2009”), while foreign companies already chosen include many of the ARJ-21 partners: General Electric, Hamilton Sundstrand, Honeywell, Liebherr Aerospace and Parker Hannifin (based on respective company press releases).

DOI: 10.14267/phd.2016013

The Chengdu and Shenyang plants at the same time continued to produce enhanced versions of existing fighter jets and introduced new models, such as the Chengdu J-10[126] or the FC-1 *Brave Dragon.* This latter aircraft is a joint development project with Pakistan and is intended for low-cost military markets (Medeiros 2005) [127]. A fighter-bomber (JH-7) was developed in Xian during the 1980s and 1990s. Both the existing stock of aircraft and the latest developments represent is at least one generation behind the technological capabilities of the US while onboard systems and mass-production capabilities are still further behind. But the real competitor of China is not located in America but in Asia: "Right now, the only arms race China is really facing is with India, and [Beijing is] winning," quotes the influential industry journal *Aviation Week and Space Technology* [128] with regard to the development of a fifth generation stealth fighter.

4.3.7 Interrupted innovation in the Chinese aerospace industry

4.3.7.1 Summary of the transition

There were two different types of interruptions in the development trajectory of the Chinese aircraft industry. At the time of the first interruption that occurred during the initial learning years, a sectoral innovation system hardly existed. China was over-reliant on one single external technology source and the vulnerabilities of such an arrangement became clear as soon as this channel "dried out". Not until a new system was established (including educating, training efforts) could the tacit knowledge be recovered through reverse-engineering. But the inherent limitation of switching to an inward-looking strategy at such an early phase of development was that the innovation performance frontier remained unchanged (if not reduced). Yet this system was rather stable for more than three decades due to a variety of reasons. The national innovation system did not undergo radical changes, and the major actors and their incentives to innovate remained largely unchanged.

---

[126] The J-10 is an F-16-class fourth generation light fighter jet with fly-by-wire control and a Russian engine, launched in 1988, first flew in 1996. It is believed to have received direct technological input from the Israeli Aircraft Industries' discontinued *Lavi* program (which received input from the F-16 program), though it was denied by both parties as it would imply American technology transferred to China. (Medeiros, 2005 and "Chinese J-10 'benefited from the Lavi project", *Jane's Defense News,* 19 May 2008; http://www.janes.com/news/defence/jdw/jdw080519_2_n.shtml)

[127] The aircaft's Pakistani designation is JF-17 *Thunder*, and development partners included Chengdu Aircraft Industries Corp., the Pakistani Air Force and Pakistan Aeronautical Complex; is equipped with a turbofan engine from the Russian Klimov. Design began in 1994 but the aircraft first flew only in 2003, produced in limited numbers since 2007/8 in China and Pakistan, while modifications are still underway.

[128]. "China Promises New, Advanced Fighter", *Aviation Week and Space Technology*, 24 Nov 2009.

DOI: 10.14267/phd.2016013

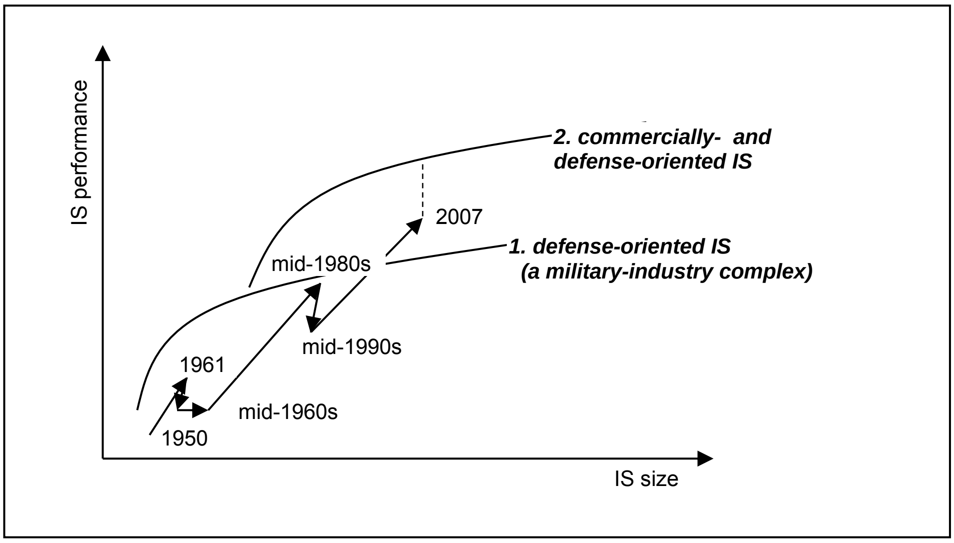
The crisis of the inward-looking innovation system was caused by exogenous political and macro-economic changes in the environment in which forces endogenous to the innovation system played little if any role. The interruption can almost entirely be explained by China's transition to a market economy. Yet the speed of the transition that took place in the aerospace industry was much slower than in many other industries that have become globally competitive by today. This points to sector-level institutional explanations. Even if market institutions only emerged gradually in the Chinese economy, the aerospace industry showed excessive institutional inertia. This of course hardly comes as a surprise in an industry that employed hundreds of thousands of employees, and where the role of the military remains influential. On the one hand, export is a good indicator of the transition; both in terms of total values and composition of the product portfolio. As the export of military planes dropped, parts and components slowly replaced and overtook them (Figure 4.15), revealing a greater integration in global supply chains. Increasing labor productivity since 2000 (Figure 4.18) on the other hand shows learning in the new system created during the transition.

However, it is a Chinese peculiarity that old structures still survive parallel to new ones in a dualist style, even within regional clusters. This is due to the privileged position of national defense on the political agenda. The incentives differ hugely for units producing for the export markets and those for closed military installations. Openness in the innovative process has clearly increased in the commercial segment, indicated by the large number of foreign partners involved in the ARJ-21 project (and the readiness to involve foreign aviation authorities in the design phase). Self-sufficiency is not an imperative anymore, even if a techno-nationalist rhetoric remains in place. However, foreign ownership of private enterprises is only allowed to a limited extent and excessive bureaucracy is still seen as a barrier to innovation. Military aircraft design and manufacturing remains still very closed and primarily domestically oriented. The transition mostly affected the civilian segment but left many areas open for further, incremental adjustments (i.e. 50% state ownership and approval requirement hinders fast corporate decision-making).

The transition was governed (and cushioned from shock) by the government. But top-down forces (changed strategies and incentives) were met with initiatives of foreign producers who were ready to enter into offset deals to produce parts locally or even to bring final assembly to China. This, in the end, shows that the transition was carefully constructed in order to support the accumulation of technological capabilities.

DOI: 10.14267/phd.2016013

Figure 4.19 Interruptions and transition in the Chinese aircraft innovation system



(Author's compilation)

The evolution of the innovation system and the interruption is summarized in Figure 4.19. The most relevant break in the trajectory (disregarding the Sino-Soviet Split of 1961 and smaller, "uncharted adjustments" over the 1970s) is the interruption in the mid-1980s that lasted until the mid 1990s (the years given in the figure are only approximate in the case of the innovation system). The drop in the performance of the system refers to a drop in exports and value added as an ultimate indicator, even if some new (or modified) products were introduced during this period. The change in the size of the innovation system involves a slight contraction based on the assumption that military financial input into innovation decreased as the budget constraints became tighter and as foreign capital was not yet available. The number of employees working on innovation was also reduced. Even if the employees stayed within the same factory, many were reassigned to non-aviation engineering and design activities. Subsequently both public and private funding increased and so did innovative performance (as shown by an increase in labor productivity and exports).

4.3.7.2 Remaining institutional challenges

The aggregate, industry level figures hide much of the details and internal structural changes and remaining hurdles that make the transition process last so long. Detailed information is still unavailable, but we can to point out the main institutional challenges and blockages that impede improvement in the performance of the sectoral innovation system.

DOI: 10.14267/phd.2016013

1. **Ownership:** Decision making in the state-owned conglomerates remains slow and heavily influence by political considerations; foreign ownership in the sector is generally limited to less than 50% (exceptions are the case assembly facilities of Embraer and Airbus).
2. **Competition:** There is little competition between the producers.[129] Military procurement policies create sufficient domestic demand for local products. The latest Chinese products have yet to make gains on the export markets. Competition does not appear to provide any incentives for the rather well-cushioned R&D institutes. Interactions between users and innovators are not very intensive. It is unclear how much freedom various plants and R&D institutes have in defining the directions of research on new technologies and to what degree is there a domestic competition for government funds. The protective measures continue to keep the industry's marketing capabilities at a less advanced level, but this is compensated for by the size of the domestic market.
3. **Access to technology:** the arms embargo by the USA and the EU remains to be a major restriction on the flow of technology.[130] Technology flows between military and civilian projects are expected to be limited, although interaction among the geographically dispersed units appears to be increasing in both domains.
4. **Flow of skilled labor:** labour compensation in the aerospace industry is not competitive with wages in coastal cities and foreign-owned enterprises; salaries are often still not determined by performance (Medeiros 2005). Considering international flows, brain drain is more common than brain gain.

The transition of the innovation system will remain incomplete as long as many of these barriers are in place. The speed of institutional change is defined by the government (and the PLAAF) which is pursuing a strategy of slow transition. As long as the industry continues to grow at more rapidly than other industries and as long as the government has no problem in raising the vast sums for new R&D projects, there will be no incentives to make changes in the innovation and production system.

[129] Military production appears to be divided by "market segment" served: light fighter jets are produced in Chengdu, heavy fighters in Shenyang, bombers in Xian; commercial projects are shared among the biggest factories.

[130] The EU appears to be more flexible in its interpretation of the embargo and is more ready to consider a reform. See more details at Sipri "EU arms embargo on China", (URL: www.sipri.org/research/armaments/transfers/controlling/arms_embargoes/eu_arms_embargoes/china)

DOI: 10.14267/phd.2016013

4.4 SINGAPORE

4.4.1 Introduction

With a total area of 697 square kilometers, with natural resources limited to the strategic waterways of the Strait, the deepwater ports and fish, Singapore may seem like an odd location for specializing in aerospace manufacturing. But history has proven that the size of the domestic market is not necessarily a limit to success and that a well-functioning innovation system can also be built around repair and production in the lower tiers of the industry. Today Singapore is the second-largest latecomer aerospace producer in the emerging world in terms of value added and is outperforming even Brazil. Between 1977 and 2007 production in Singapore grew almost constantly, with the exception of only three years. This is highly remarkable for an open economy in such a volatile sector. The reason why Singapore managed to rapidly respond to crises indicates the existence of a flexible national as well as sectoral innovation system.

4.4.2 Background: industrialization and innovation in Singapore

By the end of the 1970s when the government of Singapore decided to promote the development of the aerospace industry, the manufacturing sector had already strengthened in the country. The two fundamental conditions for earlier industrial growth were, according to Aw (1991), political stability and an investor-friendly business climate. The People's Action Party (PAP) has been continuously ruling Singapore with a high approval rating[131] since before the island state's independence from the Federation of Malaysia in 1965. A system of centralized decision making was established that prioritized economic competitiveness and efficiently fought corruption. National security was a high priority after the independence of Singapore given the not-so-friendly relations with its neighbors in the initial years. The Economic Development Board (EDB) was established in 1961 for strategic planning and investment promotion. An Export Promotion Center was created in 1965 to provide export financing and credit insurance to exporters. Trade unions were kept under control by an umbrella organization which was incorporated into the PAP structure since 1964. The 1968 Employment Act strengthened the power of employers and reduced the scope of collective bargaining for employees, but a tripartite forum, the National Wages Council was a main tool to incorporate workers in long-term growth negotiations since 1972.

[131] The party's approval rating was 47% in 1963 and climbed to 84% already by 1968.

DOI: 10.14267/phd.2016013

Aw (1991) emphasized that public housing for middle and lower classes was significantly reduced social tensions, and workers subscribed to investor-friendly reforms given a culture that valued thrift, readiness to change and social mobility, a free enterprise market, and consistent, predictable and rational policy making. The pro-industrialization policies had tangible results. The average annual growth rate was 13.2% between 1968 and 73, and 8.5% between 1974 and 82. This took place along structural transformation, in which the share of industry in GDP increased from 19% in 1960 to 30% in 1980, and the share of manufacturing in GDP increased over the same period from 13% to 22.3%. In the 1960s, around half of the domestic investment was financed by national savings, which increased to over two-third from the 1970s. Foreign investment was most pervasive in the manufacturing sector, increasing from 45% in 1966 to 81% in 1979. This was also spurred by the externalization of the American economy and an explicit US strategy to develop Southeast Asia to contain Soviet influence in the region.

Singapore followed a strategy of export promotion and has targeted "non-traditional" industries already since 1959. There was a shift in the promoted industries toward technology-intensive sectors (shipbuilding, electrical and non-electrical machinery, appliances and supplies, and transport equipment) in the mid-1970s. With the provision of loan subsidies, two-third of all loan commitments went into the promoted sectors by 1975.

Education was aimed at technical and vocational training in order to create broad basic skills foundation. On-the-job training was a major tool. Since the early 1970s Singapore achieved near-full employment and migration policy was highly regulated to follow business cycles and skills demand.

Put simply, Singapore's economy underwent two major transformations over the last four decades. In the late 1970s, it shifted from labor-intensive to capital-intensive, high-value-added manufacturing. Responding to increasing competition in the region and the lack of natural resources, Singapore recognized the need to shift to knowledge-intensive activities and services which occurred at the beginning of the 1990s. Explicit innovation policies and strategies were devised by the EDB and a National Science and Technology Board (NSTB) was established in 1991 to implement them in 2-year technology plans. The government was also pushing for reforms in higher and vocation education. Already since 1978 Singapore has been systematically monitoring R&D activities. In the 1990s, strong incentives were offered to boost total R&D expenditures

DOI: 10.14267/phd.2016013

to above 2% of the GDP by the year 2000. A national innovation system relied on intensive interactions between the private sector, the EDB (which was responsible for innovation and FDI strategies), and the NSTB (which was renamed to Agency for Science, Technology and Research or 'A-Star' in 2002). In this structure, strategic planning meetings were held regularly since 1987 and competitive challenges could be reacted upon rather quickly. Information exchange was also intensive between employers, employees and the state agencies in a corporatist, tripartite structure (Yun 2004).

Table 4.3 Main indicators on the national innovation system of Singapore, 1990-2009

	1990	1995	2000	2005	2009
Gross Expenditure on R&D (USD mln)a	382	780	1,746	2,658	3,271
GERD / GDP (%)	0.81	1.11	1.85	2.19	2.28
Business Expenditure on R&D / GDP (%)	0.44	0.71	1.15	1.45	1.41
Researchers in Science and Engineering	4,329	8,340	14,483	21,338	26,608
Patents Owned	n.a.	256	1,268	3,475	6,067
Scientific and technical journal articles	572	1,141	2,361	3,611	3,792b
Hi-tech exports' share in Mfg exports (%)	39.7	53.9	62.6	56.6	50.8c
		Average Annual Growth rates (%)			
		1990-95	**1995-2000**	**2000-05**	**2005-09**
Gross Expenditure on R&D		15.3	17.5	8.8	5.3
GERD / GDP		6.5	10.8	3.4	1.0
Business Expenditure on R&D / GDP		10.0	10.1	4.7	-0.7
Researchers in Science and Engineering		14.0	11.7	8.1	5.7
Patents Owned		n.a.	37.7	22.3	14.9
Scientific and technical journal articles		14.8	15.7	8.9	2.5
Hi-tech exports' share in Mfg exports		6.3	3.0	-2.0	-3.5

Sources: National Survey of R&D in Singapore 2009, Agency for Science, Technology and Research; World Development Indicators Online
Notes: a) USD million in constant 2000 prices; b) Data refers to 2007; c) refers to 2008

Table 4.3 gives a general overview of the results of the innovation policies. Between 1990 and 2009 R&D expenditures increased 6-fold. Compared with GDP, total R&D expenditures increased from 0.81 in 1990 to 2.28. After the rapid growth in key dimensions of the innovation system in the 1990s, there is a slow-down in the new millennium, but the growth is still impressive in light of the several crises that hit the outward-oriented economy over the last fifteen years, from the Asian financial crisis through 9/11 and the SARS crises to the most recent global financial crisis.

DOI: 10.14267/phd.2016013

4.4.3 The development trajectory

4.4.3.1 The emergence of the industry (1970s – 1980s)

From the early 1970s onwards, Singapore capitalized on the growing demand for aircraft servicing and maintenance over the years of economic growth of the island[132]. Aerospace was given a priority industry status due to its high value-added, skill intensive nature (along other industries such as electronics, computers or medical equipment). The government formulated a more realistic aim for aerospace manufacturing than neighboring Indonesia. In addition to servicing the fleet of the Republic of Singapore Air Force (RSAF), companies were to build up capabilities in commercial maintenance, repair and overhaul (MRO), and parts and component manufacturing. Also, Singapore was to become the regional aviation headquarters for Southeast Asia. This was intended to provide a mixed source of technology and investment in the emerging industry. RSAF was an important customer for maintenance and upgrade services of its fighter and trainer fleet, and the growing East Asian commercial aviation market was supposed to provide demand for a new regional MRO hub that could benefit from its strategic location.

However, attracting foreign investors did not prove to be very successful during the 1970s. According to Hill and Pang (1988), this could be explained by four factors: (1) lack of a regional market for components; (2) difficulty in sourcing raw materials; (3) lack of a bilateral agreement with a foreign certifying authority (e.g. the Federal Aviation Authority of the US);[133] and (4) uncertainty about the availability of skilled labor force.

The government's systemic response was a reform package in 1979. Incentives were offered to invest in the priority industries, including corporate tax exemption for the first five years after production start-up.[134] In order to attract a skilled labor force, a corrective wage policy was implemented and education and training institutions were expanded, especially in fields of science and engineering. A bilateral Airworthiness Agreement was signed with the US in 1981 to mutually accept national certification.

[132] During the 1960s, Singapore was still a low-cost manufacturing location with a rather low industrial base. According to Wong (2003) manufacturing accounted for 13% of GDP in 1960 and 28% in 1980.
[133] Without an agreement to mutually accept national certification, companies had individually to obtain certification from national and foreign authorities. For instance, the predecessor of ST Aerospace became an FAA certified repair station in already in 1973.
[134] "Singapore attracts more" *Flight International* 4 Jan 1986

DOI: 10.14267/phd.2016013

Further important steps were the organization of the Asian Aerospace Exhibitions starting in 1981 and the opening of a new airport at Changi.

In 1981, aviation contractor firms formerly owned by the Ministry of Defense were reorganized into the newly formed Singapore Aircraft Industries (SAI). SAI consisted of five subsidiaries and two associate companies.[135] The most important of these was SAMCO, which was established in 1975, with a profile in avionics and systems overhaul. As shown in Table 4.4, SAI has quickly accumulated capabilities to upgrade fighters and trainers and manufacture trainers and helicopters under license. It was assigned to refurbish Douglas A-4 fighters and trainers. By 1985 it had modernized some 80 plains of this type for the RSAF. In 1985 it was the first company outside Italy to receive a license to assemble the Marchetti S-211 jet trainers. In 1986 SAI also successfully accomplished the re-engining of an A-4 with a General Electric (GE) turbofan. The company was subsequently contracted by the RSAF to re-engineer and upgrade avionics on another 50 of these fighters and trainers. During the early 1990s, further refurbishment programs involved converting 28 F-5 fighters to reconnaissance configuration and upgrading the rest of the fleet with state-of-the-art radar, avionics and weapons delivery systems.[136] The refurbishment upgrading projects provided opportunities for technological collaboration with a number of established aerospace companies, including Douglas, Northrop and GE from the US and Aermacchi and Galileo Avionica from Italy.

Already by the end of the 1970s SAMCO and the Helicopter Division of French Aerospatiale established a joint venture (Samaero) at the Seletar Airport to provide helicopter maintenance services in the region. The oil exploration activities in the region and military procurement by RSAF offered a growing market for utility helicopters. An important milestone was the local assembly of 17 Aerospatiale’s medium-sized AS-532 *Cougar* and AS-332 *Super Puma* models from kits between 1985 and 1988. During 1991-92 the smaller AS-350 *Squirrel* and 550 *Fennec* helicopters[137] were assembled from kits in Singapore.

---

[135] These included: Singapore Aerospace Maintenance Company (SAMCO), Singapore Aerospace Manufacturing (SAM), Singapore Aero-Components Overhaul Company (SACO), Singapore Electronics & Engineering Ltd (SEEL), Singapore Aerospace Warehousing and Supplies (SAWS), Singapore Aero-Engine Overhaul Ltd (SAEOL), and the Samaero company (“Singapore attracts more” *Flight International* 4 Jan 1986).

[136] For details see “Gradually Global” *Flight International: Asian Aerospace Special* 19-25 Feb 1992

[137] The AS-332 and -532 models, as well as the AS-350 and -550 models are structurally the same; the designation AS-5.. indicates military use, AS-3.. indicates civilian use.

DOI: 10.14267/phd.2016013

At the same time, investment incentives as well as the rapidly increasing volume of passenger- and cargo air traffic had positive effects on the commercial segment of the industry. Between 1973 and 1990, air freight increased at an average rate of 20%, the number of passengers carried increased at an average rate of 11% (see Table 4.5). In the aerospace sector, the number of firms doubled to 18 between 1980 and 1985.

DOI: 10.14267/phd.2016013

Table 4.4 Major local assembly and upgrading projects at ST Aerospace (1974-2007)

Aircraft Model	Collaborating Company (HQ Country)	Total Nr. Built	Years of Production	Notes
Fighters/Trainers				
A-4B *Skyhawk*	Douglas (USA)	32	1974-77	modernized with US components
A-4C *Skyhawk*	Douglas (USA)	40[u]	1980-81	modernized with US components; license received from Douglas
A-4B *Skyhawk*	Douglas (USA)	8[u]	1983-84	upgraded with US components to trainers
S-211 trainer	Marchetti /Aermacchi/(I)	24	1984-87	assembled under license
A-4B *Skyhawk*	Douglas; General Electric (USA)	24	1989-90	Re-engined; modernized with US components
F-5 *Tiger*	Galileo Avionica /Finmeccanica/ (I); Elbit (ISR)	28 40[u]	1990 1994-	Converted to reconnaissance configuration Upgraded with new radar, avionics and weapons systems; Subsequently (1998) offered upgrade service to Turkey and Brazil
F-16C/D	BAe Systems (UK)		1996-	Cockpit avionics upgrade to '*Falcon One'*
Transports				
C-130 *Hercules*	Rockwell Collins (USA)	10	2007-(14)	Avionics; systems upgrade (also exports upgrade service for Indonesia)
Helicopters				
AB-205	Bell (USA)	6	1984	Modernized; second-hand from Bangladesh and Kuwait
AS-332, *Super Puma*, AS-532 *Cougar*	Aerospatiale /Eurocopter/ (F)	17	1985-88	assembled from kits under license
AS-350 *Squirrel*, AS-550 *Fennec*	Aerospatiale /Eurocopter/ (F)	20	1991-92	assembled from kits under license
EC-120	Eurocopter (EU) and CATIC (PRC)		1990-	Co-development; 15% stake
AS-332 *Super Puma*			2002-	Upgrade

Notes: (u) number is unconfirmed; ST Aerospace includes Singapore Technologies Aerospace and its predecessors
Sources: SIPRI; *Flight International*, various articles

Table 4.5 Growth of passenger and cargo air traffic in Singapore, 1973-2012

	1973	**1985**	**1990**	**1995**	**2000**	**2010**	**2012**
Registered carrier departures	21,300	31,100	30,500	51,600	71,042	128,829	154,429
Passengers carried (million)	1,249	4,912	7,046	10,779	16,704	24.8	29.1
Air freight, (million ton-km)	68	981	1,652	3,687	6,005	7,724	7,507

Source: World Development Indicators Online

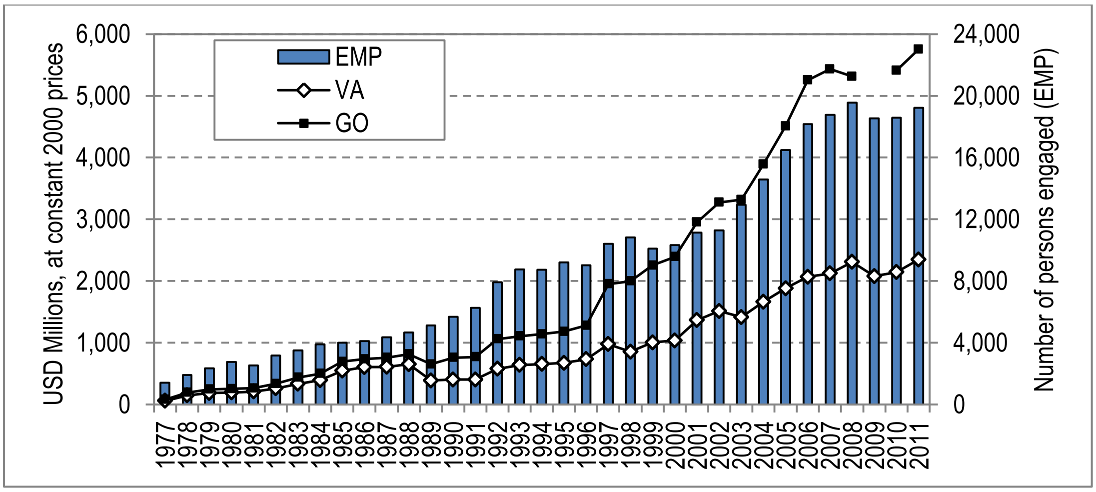
Employment in aerospace increased from 2,761 workers in 1980 through 4,000 in 1985 to 5,676 in 1990. Competitive wages (with an average annual growth of 9% between

DOI: 10.14267/phd.2016013

1981 and 1985) attracted large numbers of foreign staff during the initial years, who were slowly replaced by locally trained skilled labor. As Figure 4.20 shows, aerospace production (which includes MRO as well as parts and components manufacturing) increased substantially during the early years. In 1980 aerospace value added was 192 million US dollars, in 1985 it was 545 million, and it peaked at 651 million in 1988, with an average annual growth of 17% over the period 1980-88. Between 1980 and 1985 exports increased from 106 to 355 million US dollars, at an average rate of 29% per year. By 1990 Singapore's exports increased to 528.7 million dollars. Singapore was still a net importer, mainly due to the new aircraft and equipment purchases of Singapore Airlines. According to Pang and Hill (1992) aerospace imports were more than 50% higher than exports in 1981 and 1985.

The aerospace industry's performance was equally remarkable in comparison with other latecomers. In 1983 Singapore forged ahead of the aircraft designer Brazil in terms of value added (332 vs. 301 million US dollars). The difference is even greater in terms of labor productivity, given that Singapore achieved this value added level with 1/3rd of the labor force of Brazil. Already by 1981 the level of labor productivity in the latecomer Singapore (81.1 US dollars per person engaged) was higher than in the US (72.9). This was of course achieved by concentrating on the MRO segment and on one cluster, while the US had a more diverse structure.

Figure 4.20 Gross Output, Value Added and Employment in the Singapore Aerospace Industry, 1977-2011



Sources: UNIDO, Hill and Pang 1988, Singapore Statistics

DOI: 10.14267/phd.2016013

Box 6.1 Introduction to the civil aircraft maintenance, repair and overhaul market

The civil MRO market comprises of four segments. We provide a brief overview of the nature and frequency of the work they entail, the cost structures, and the type of companies involved in the activity.

Airframe heavy maintenance refers to what is called as "C and D-checks" in commercial aviation. C-checks include a detailed inspection of the airframe and aircraft components, and corrosion prevention. C-checks are due after 2,500-3,000 flight hours and may require 2 to 4,000 man-hours work, usually takes 3 days. D-checks refer to a comprehensive structural inspection and overhaul of the aircraft and can take up to 30 days, depending on the size of the aircraft. Since airlines can hardly afford keeping planes on ground for such a long period, they divide the work and carry out the inspection and overhaul in the form of 'C1-C4-checks'. All of these operations are carried out mainly by aircraft operators directly or through a subsidiary (still around 75% of the global MRO industry), and by independent MRO providers. Airframe heavy maintenance accounts for around 18% of global MRO turnover, nearly 70% of which is labor cost and 20% is material costs, such as solvents, fasteners and standard parts and airframe parts. Replacement parts, or "rotables" are often provided by airlines.

Line maintenance refers to the most frequent, lighter checks carried out on a daily basis in order to ensure that the aircraft remains flight worthy. These are the so-called transit checks, daily and weekly checks, A and B checks, which include simple visual checks, trouble shooting, defect rectification, overnight maintenance and component replacement. Providing these services accounts for one-fifth of all MRO revenues. Line maintenance is almost entirely done by airlines themselves. In about 10-15% of the cases they outsource it to subsidiaries or other contract agents. This is overwhelmingly a labor-intensive work, material costs incur expendables and consumables.

Engine overhaul is the largest segment, accounting for around 40% of global MRO turnover. It aims at restoring designed operational conditions of an engine according to performance guidelines established by the manufacturer. This is carried out by disassembling, inspecting the engine, repairing or replacing of parts if needed, re-assembly and testing. Some "life-limited parts" have a prescribed replacement interval; otherwise engine overhaul takes place on an as-needed basis. The frequency of engine overhauls varies largely, between 4.5 and 24 thousand engine hours, similarly to the costs, which could vary between 0.45 and 5.5 million dollars. Materials account for almost two-third of the costs. Engine overhaul is carried out mainly by original equipment manufacturers (44%), followed by aircraft operators (25%), independent companies (13%, such as ST Aerospace, or Standard Aero, MTU, SR Technics, Aerothrust, etc.) and airline subsidiaries (18%, i.e. Delta Tech-Ops, Air France Industries and Lufthansa Technik).

Component maintenance, repair and overhaul activities amount to around a quarter of the global MRO industry. These involve the maintenance, repair and overhaul of the main systems, including wheels and brakes, avionics, auxiliary power unit (APU), fuel systems, hydraulic power, flight controls, thrust reversers, landing gear, electrical systems, on-board environmental control and entertainment and other systems. Wheels and brakes are exposed to the heaviest duty and this is the largest cost item in MRO, followed by avionics and APU. These three activities account for 45% of the segment's turnover. Component MRO is the sub-market with the lowest concentration of firms, given the relatively higher competition on lower tiers in the aerospace supply chain. Original equipment manufacturers are the most important actors in the APU, avionics and fuel systems sub-segment, the rest is dominated by airlines

DOI: 10.14267/phd.2016013

providing in-house MRO or outsourcing it to subsidiaries or independent firms. Material costs are more important than labor costs when it comes to component MRO, especially in the case of wheels and brakes, APU, hydraulics and flight control systems and fuel systems. The most labor-intensive activities are electrical, landing gear and thrust reverser MRO. Specialist services are most important in the avionics sub-segment.

Source: Aeronautical Repair Station Association, 2009, "Global MRO Market Economic Assessment"[138]

4.4.3.2 The emerging sectoral innovation system

By the late 1980s, the Singapore aerospace industry accumulated capabilities to locally assemble older generation fighter and trainer aircraft, learned to upgrade them in collaboration with US manufacturers. It also gained capabilities to assemble and repair helicopters. It became a competitive MRO hub in South East Asia, receiving certifications not only for aircraft in the fleet of RSAF but also for the growing civilian fleet of the state-owned Singapore Airlines[139].

Evidently, aerospace firms in Singapore were actively learning to apply advanced technologies to assemble and modify technologically complex aircraft that were at least 'new to the country'. MRO firms of Singapore learned to work efficiently and at competitive rates. For a comparison, repair and overhaul man-hours were reported to be 16-25 US dollars in Singapore, in comparison with 25-50 dollars in the US and 30-45 dollars in Europe.[140] From the 1980s the industry depended not only on military demand but also on the rapidly growing commercial market. The primary channels of technology acquisition were foreign direct investments and licensing. The 1980s brought capabilities through foreign investment, especially from the US (air frame structures, systems and equipment MRO, manufacturing of turbine blades, compressors and landing gear). Singapore Aerospace was the main military producer, but a number of other transnational companies such as Sundstrand, Honeywell and Aerospatiale (Eurocopter) located a regional headquarter in Singapore which increasingly used local suppliers for production of smaller parts and the provision of engineering services.

The emerging sectoral system of innovation in aircraft was embedded in an emerging national innovation system which provided a strong knowledge base in science and engineering, access to foreign experts but also to a growing pool of locally educated, competitive workers. The government provided strong incentives for start-up

---

[138] URL: http://www.arsa.org/files/ARSACivilAircraftMROMarketOverview-20090821.pdf; retrieved: 18 Feb 2011

[139] The Engineering Division of Singapore Airlines was responsible for the maintenance of its fleet which by the end of the 1980s consisted of Airbus A300s, A310s, B747-200 and -300s, B757s and DC-10s.

[140] "Singapore aerospace sprouts wings" *Aerospace America*, October 1986

DOI: 10.14267/phd.2016013

companies in forms of tax holidays, investment allowances, training grants and investment guarantees. The Loyang Industrial Estate near Changi airport was the first aerospace industrial park which provided ready-built premises and a good infrastructure for new companies. The strong education system offered a full spectrum of vocational, technical and engineering programs.

The emergence of the national and the sectoral innovation systems were carefully designed by the government with a goal to benefit from high-value added, high-wage jobs in engineering-intensive activities. The sectoral system was designed to make benefit of Singapore's geographical location. These included the economic and air transport growth in the Asia-Pacific region, the cultural connections with China, and airlines' need to cut costs through a low-cost maintenance location and product support center.

Evidence that the innovation system has emerged is indicated by its ability to manage its knowledge resources in times of economic shocks. The system, unlike in any other emerging countries, learned quickly to react and shift to new, more competitive areas.

4.4.4 Interruptions

The most intriguing feature of the emergence of the aircraft industry of Singapore is the absence of long-lasting crises during the 1980s and 1990s. The sector was rather successful in avoiding two potentially severe crises of macroeconomic origin. In 1985, the disproportionately larger growth of wages compared to productivity caused a decline in competitiveness and slowed down export growth and foreign investments. Hill and Pang (1988) argued that apart from a drop in exports and imports, the industry was relatively unaffected, owing to the instant intervention of the government. We can also see that trainer upgrading and helicopter assembly activities provided sufficient orders for the industry during this time. The crisis had no effect on value added, which was in fact growing by 38.5% in 1985 primarily due to the defense industries. The Asian financial crisis of 1997 had also relatively limited impact on Singapore in comparison with its impact on aircraft innovation systems in other countries (see below).

DOI: 10.14267/phd.2016013

Table 4.6 General Statistics of the Singapore Aircraft Industry (1977-2011)

Year	Value Added (USD mln)	Gross Output (USD mln)	Empl.	Labour prod.; (1000 USD/ emp.)	Wages / Empl. Change (%)	Invest-ments	Business R&D (USD mln)	Number of firms	Export Total	Export Parts and components	Imports
1977	58	77	1,400	41.8		30.1					
1978	146	193	1,900	76.9		11.6					
1979	185	244	2,340	79.0		36.6					
1980	192	253	2,761	69.4		18.2			106		
1981	207	262	2,535	81.8		36.8		10	99		
1982	261	335	3,169	82.3	10.4	79.1		11	149		
1983	332	435	3,494	94.9	1.6	6.4		17	220		
1984	393	499	3,898	100.8	14.0	37.9		17	255		
1985	545	692	3,998	136.2	9.7			18	355		
1986	605	733	4,111	147.1	-7.6			19	0		
1987	607	757	4,343	139.8	5.5			21	0		
1988	651	814	4,659	139.7	2.9			20	419		
1989	388	650	5,121	75.8	3.0	75.0		22	642	338	1,604
1990	403	759	5,676	71.1	1.5	102.6		26	529	347	1,211
1991	403	769	6,259	64.3	6.3	81.4		29	394	290	1,633
1992	575	1,057	7,915	72.7	23.3	178.9		32	402	348	1,769
1993	638	1,105	8,745	72.9	-1.9	160.1		33	285	270	1,989
1994	653	1,138	8,736	74.7	5.6	130.1	7.9	36	259	218	1,806
1995	673	1,179	9,214	73.0	2.4	108.5	7.2	39	414	292	1,824
1996	732	1,278	9,012	81.3	5.8	83.7	4.4	39	575	410	3,213
1997	974	1,949	10,402	93.7	1.4	92.3	9.4	45	705	553	3,381
1998	854	1,997	10,831	78.9	-3.3	128.8	14.7	40	619	488	2,686
1999	1,004	2,255	10,093	99.5	19.7	146.3	12.2	43	488	456	2,281
2000	1,034	2,391	10,334	100.1	1.9	160.8	11.7	44	670	534	1,152
2001	1,364	2,951	11,142	122.4	-5.0	232.7	11.2	46	831	455	3,721
2002	1,513	3,273	11,278	134.2	9.3	159.1	18.4	49	901	526	3,018
2003	1,414	3,316	12,931	109.4	-0.4	170.7	22.0	54	1,122	744	3,654
2004	1,662	3,892	14,584	114.0	2.9		11.0	68	1,141	952	3,655
2005	1,880	4,508	16,493	114.0	-3.6		15.0	63	1,334	993	3,325
2006	2,067	5,253	18,169	113.8	1.2		16.5	68	1,987	1,609	5,021
2007	2,121	5,432	18,777	113.0			19.0	59	2,580	2,090	4,969
2008	2,071	5,314	18,115	114.3			35.0	70	3,057	2,582	7,142
2009	2,078		19,545				32.9		3,233	2,927	6,284
2010	2,142	5,410	18,529	115.8					3,692	3,453	4,390
2011	2,347		18,581								

Sources: Singapore Statistics; UNIDO; A*STAR Singapore
Notes: values in US dollar at constant prices

4.4.5 Smooth transitions

By the time the global industry faced by far the most severe crisis in 1990, Singapore had already initiated a fundamental overhaul of its aerospace industry and innovation

DOI: 10.14267/phd.2016013

system. The overhaul was triggered by the declining sales and value added experienced in 1989 due to the underperformance of the military segment. In 1989 value added dropped below 1984 levels, sales below 1985 levels, labor productivity declined by 46% in a single year. Singapore was quick to realize that the global competitive environment was transforming towards greater internationalization. It also saw the limits of its domestic market and the growth potential of the Asia Pacific region. This realization led to a new strategy which implied steering away from the defense industries and expanding the commercial segment. Singapore rather swiftly and efficiently introduced measures to rejuvenate its aerospace industry by privatization, reorganization and internationalization of its largest holding, Singapore Technologies[141].

In order to finance further expansion, the government privatized a third of its stake in Singapore Technologies Aerospace (ST Aero) in June 1990. The offering was highly successful (shares were 33 times oversubscribed) and raised 150 million SGD[142], almost equal to the company's annual turnover. Commercial maintenance activities were shifted to a spin-off company, Singapore Aviation Services (SASCO) before the partial flotation. At the beginning of the 1990s, more than 2/3rd of ST Aero's business was coming from the defense segment. The aim was to increase commercialization and increase foreign sales. ST Aero's turnover from foreign operations was already as high as 32% by 1989. This increased to 50% by 1990.[143] In 1990, the company set up ST Rotables at Stansted Airport in the UK. In 1991 it established a 20 million US dollars green-field investment in Mobile, Alabama to offer commercial maintenance and cargo conversions for Fedex. It also established operations in Los Angeles by acquiring a local sheet-metal supplier of Boeing with an aim of moving closer to its customers.

ST Aero also took a major step in venturing into a new area of co-development. It signed a deal with the French Aerospatiale (now Eurocopter) and China National Aero-Technology Import and Export Corporation (CATIC) to jointly develop a 5-seat helicopter, the EC-120 (original designation P120L). The joint venture started in 1990. Eurocopter owned a 61% share and was responsible for the instrument panel, landing gear, seats, rotor system, transmission, final assembly, flight test and certification. CATIC (through Hafei Aviation Industry Company) owned a 24% stake and was responsible for cabin structure and doors, engine cowlings, pod central and intermediate

---

[141] In 1989 Singapore Aircraft Industries was reorganized into Singapore Technologies in line with the diversification strategy into commercial aerospace.
[142] This equals to around 100 million US dollars at 2000 prices.
[143] "Gradually Global" *Flight International: Asian Aerospace Special* 19-25 Feb 1992

DOI: 10.14267/phd.2016013

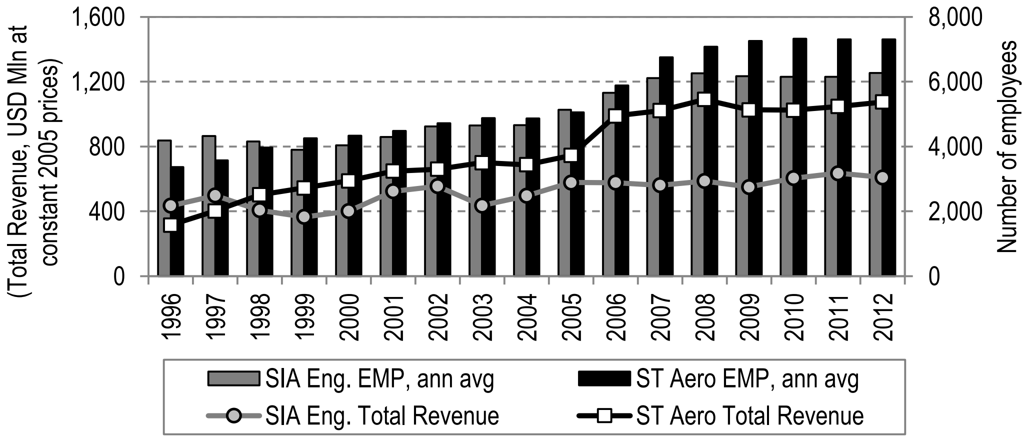
structure and fuel system. Singapore Technologies Aerospace owned 15% of the project and was responsible for tailboom, fin, horizontal stabilizer, fenestron (tail rotor), general doors and instrument pedestal development. The design was successful, but ST Aero did not participate in the production of the helicopter later on. Instead, it took on duties in line with what it was doing before: MRO and aircraft refurbishment. In the mid-1990s it upgraded the F-5 fighters of RSAF with new radar, avionics and weapons systems. In 1999 it successfully developed a method for passenger to cargo conversion of B-757s. In 2002 it entered into a strategic cooperation with BAe Systems of the UK to add new avionics suits and mission computers to some of the F-16s Singapore had acquired, resulting in the "Falcon One" upgrade. It also upgraded *Super Puma* helicopters and C-130 *Hercules* transport planes for the air force over the 1990s and 2000s (Table 4.4). In 2006 the company entered the mini UAV systems business after being contracted by the RSAF. During the 2000s, STA Aero continued the internationalization of its activities. It opened another facility in the USA in San Antonio, Texas in 2006. It entered the Chinese market (established MRO facilities in Shanghai in 2004, logistics in Guangzhou in 2007); in 2006 it acquired SAS Component A/S in Denmark and established a subsidiary in Panama. As a result of the growing on the international markets, ST Aero tripled its revenue between 1996 and 2007 and increased profits by 9-fold to 143 million dollars (Figure 4.21).

ST Aero was the largest, but by far not the only company in the industry. The number of companies in fact increased from 20 in 1988 to 33 by 1992. This increase was only partly a result of the creation of subsidiaries. This period also saw major new investment in the sector, with an average of 120 million dollars between 1989 and 1995 (Table 4.6). By the mid-1990s, major companies such as GE, Goodrich, Hamilton Sundstrand, Liebherr, Rockwell Collins or Rolls Royce Engines had established a presence in Singapore, expanding the avionics and engines knowledge base in the country. The largest competitor in the MRO industry for ST Aero was another state-owned company, Singapore Airlines (SIA). Over the years, SIA Engineering has responsible for the engineering work on the airline's expanding large aircraft fleet. In 1992, SIA's Engineering Division became a separate subsidiary, SIA Engineering, with an intention to increase foreign presence. SIA Engineering similarly expanded its MRO operations in the late 1990s and early 2000s and set foot in Australia, the United States, Hong Kong, Indonesia, Philippines and Vietnam. Between 1996 and 2007 its global

DOI: 10.14267/phd.2016013

employment increased from 4,200 to 6,100, its turnover grew from 407 to 539 million dollars (Figure 4.21).

Figure 4.21 Maintenance, repair and overhaul revenues of ST Aerospace and SIA Engineering, 1996-2012



Sources: SIA Engineering and Singapore Technologies Aerospace annual reports, various years.
Note: Constant price series converted with a 1.72 SGD/USD rate for 2000.

4.4.6 A new growth trajectory

In short, during the early 1990s, Singapore's partly state-owned companies increasingly focused on the commercial markets. They realized growth through global expansion. At the same time, the knowledge base of the industry was strengthened substantially through a focus on innovation and pre-competitive research. Targeted Aerospace R&D support programs were designed by the newly formed Agency for Science, Technology and Research (A-Star). The program defined new R&D directions: advanced materials, manufacturing processes and automation, information and communication, inspection and non-destructive testing, and computational modeling and dynamics.

It may seem paradoxical that the industry as a whole is performing well, despite the relatively low R&D inputs in comparison with other sectors in Singapore as well as with other countries. In 2009, aeronautical engineering employed less than 1% of Singapore's researchers and received hardly more than 1% of all R&D expenditures. Aircraft manufacturing companies in Singapore owned only 14 patents in the same year.[144] In an international comparison, Singapore's aerospace R&D of 2005 was 15.3 million US dollars, compared with 155.5 million of South Korea, 340 of Japan or 672

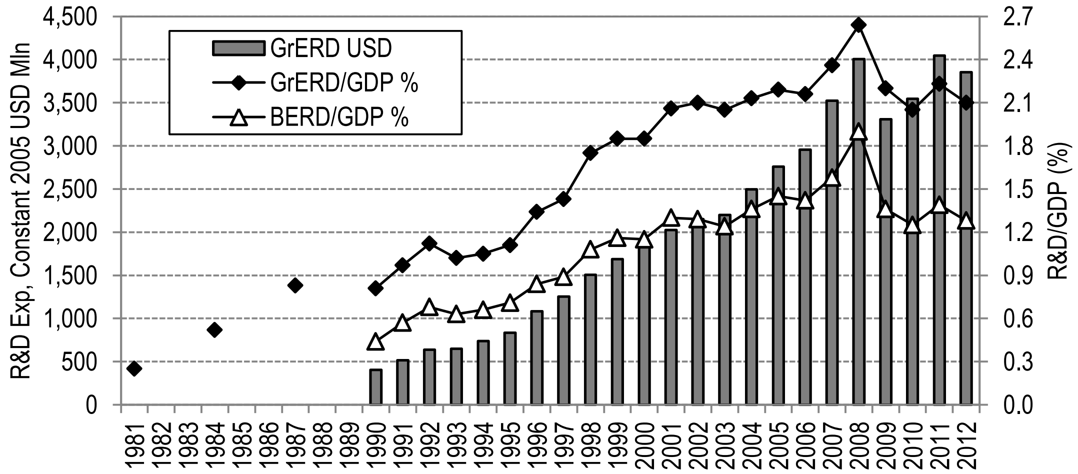
[144] National Survey of R&D in Singapore 2009, Agency for Science, Technology and Research.

DOI: 10.14267/phd.2016013

million of Canada. Remarkably, Singapore managed to establish a "low-cost" aerospace innovation system owing to its specialization in the MRO and parts and components manufacturing segments. Nevertheless, due to intensive linkages with other related industries, aircraft manufacturing in Singapore benefitted from R&D input into fields such as electronics and electric, mechanical, computer, and material science and engineering, which received around 85 percent of the 2.5 billion USD R&D expenditures.

These close linkages explain how a shift to knowledge-intensive activities occurred in aerospace in harmony with the overall shift of the national innovation system. Singapore consciously increased the national and corporate R&D during the last two decades. From 380 million dollars in 1990, gross expenditure on R&D increased to 3.4 billion dollars by 2007 (Figure 4.22). Although in comparison with other OECD countries, Singapore's aerospace R&D is relatively low (15.3 million USD in 2005, as opposed to 155 million in South Korea, 340 million in Japan or 1.9 billion in Germany), but its aerospace activities are centered around selected segments which are closely related to existing local capacities (such as avionics and the electronics industry or precision engineering and engineering capabilities in general).

Figure 4.22 The National Innovation System of Singapore - R&D Expenditures, 1981-2012



Sources: "National Survey of R&D in Singapore 2009", *Agency for Science, Technology and Research*, Singapore; Yearbook of Statistics Singapore, various editions. *Note:* Constant price series converted with a 1.72 SGD/USD rate for 2000.

A good indicator of the strong performance of the national and sectoral innovation systems is how the aerospace industry weathered the 1997 the Asian financial crisis. Due to declining demand of partners in the region, the crises caused a 12% decline in

DOI: 10.14267/phd.2016013

value added by 1998, but growth resumed the following year at an 18% rate. The reason for the quick recovery can be explained partly by the strong macroeconomic and financial fundamentals with which Singapore entered the crisis (Chia 1999). However, even if the Singapore dollar depreciated against the US dollar, it appreciated against other Southeast Asian currencies and regional demand for aerospace products (including repair) was falling. But the regional markets were declining (aerospace exports dropped by 11% drop from 1997 to 1998 and by 20% from 1998 to 1999). Yet the industry showed strength by having expanded to overseas markets, and shortfalls in regional demand were compensated for by increased military orders. On the other hand, despite the crisis, Singapore continued to increase R&D expenditures. The experience also gave incentives for companies to further expand overseas presence (see above ST Aero's strategy in the 2000s).

At the moment, Singapore's aerospace innovation system and production facilities are constantly expanding. The number of aerospace graduates has been constantly growing and is expected to reach 1,000 annually in 2010.[145] Current manufacturing activities focus on avionics and aircraft and engine parts and components. The latest incentives for investment include a 300 hectares new industrial park at a renovated airport in Seletar to be completed in 2018. Three major companies that already indicated their intention to move there and expand capacities are EADS's helicopter maker Eurocopter and the engine manufacturers Pratt & Whitney and Rolls Royce. The latter intends to bring engine parts manufacturing (wide chord fan blades), engine assembly and test work to Singapore to serve the Asian large aircraft market. This shows once again that transnational companies value Singapore's location and their contribution made Singapore a "first mover latecomer".

Singapore's future competitiveness lies in the still increasing performance of the aerospace innovation system. It can draw from a strong knowledge stock. Almost two-third of all researchers (60-64%) has been working in the field of engineering and technology in the last decade. Their number in business enterprises has been increasing substantially, from 5,841 in 2002 to 11,732 in 2007 (in terms of full time equivalent). Singapore's commitment to invest in education, training and R&D is well above the regional average. But parallel to the investment in a knowledge-based growth,

[145] This is an aggregate of all graduates from universities, polytechnics and technical institutes, and includes aeronautical engineering, avionics, aviation management and 'mechatronics'. Additionally, courses started in 2007 to expand the number of precision engineering specialists (Association of Aerospace Industries Singapore, 2010)

DOI: 10.14267/phd.2016013

Singapore’s Economic Development Board still provides incentives to invest in the MRO segment similarly to the early years of emergence.

4.4.7 Conclusion

Within three decades following its emergence, a strong aircraft industry emerged in Singapore. The sector is among the top ten in the world in terms of value added, with output levels similar to Brazil. The aircraft industry in Singapore differs from other latecomers in many ways. It did not seek prestige through producing a locally designed aircraft, rather accumulated capabilities to become a highly competitive MRO hub. Since 1980, it was one of the very few countries that managed to sustain growth in the sector. It was also one of the first Asian producers (along with Hong Kong) to benefit from the new winds of internationalization in the 1990s.

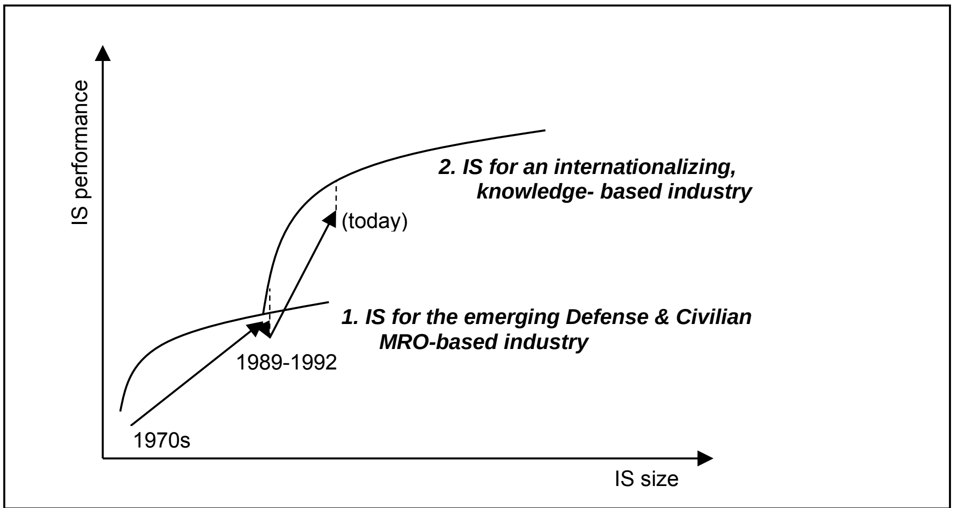
In Singapore, the emergence of the industry and sectoral innovation system was successful because of the mixed policy of developing a commercially-focused, but militarily-aided system to accumulate technological capabilities. Hill and Pang (1988) drew attention to the major differences between the way Singapore and Indonesia promoted their aerospace industries. While Singapore followed an outward-looking strategy with a strong repair and services orientation, Indonesia was inward looking, aimed at manufacturing complete aircraft for the domestic market. Singapore capitalized on its competitive advantages and relied on several firms, the Indonesian government owned a national champion which was operating in a highly politicized environment. The government’s interventions in Singapore were also “extensive” and state ownership was considerable, but it was ‘efficiency enhancing’, unlike in Indonesia. Already in 1988 the authors called attention to the vulnerability of the Indonesian aircraft industry because of its higher political dependence in contrast with Singapore.

A consequence of the outward-looking strategy was the strong competition Singaporean manufacturers and MRO providers had to face. This fostered the emergence of a sectoral innovation system early on and close interactions among the main stakeholders. Latecomers’ technological disadvantages were offset by the government’s activist industrial policy during the years of emergence. This included

DOI: 10.14267/phd.2016013

simultaneously “importing” experts[146] and training locally a competitive, skilled labour force; procuring aircraft and ordered aircraft refurbishment programs to expand technological capabilities of its leading firm. On the other hand, by building industrial parks and providing incentives for foreign investment, it laid the foundations of a strong private sector in aerospace. The specialization in MRO activities and component manufacturing and the proximity of related industries also efficiently substituted missing capabilities and became a source of innovation. The aerospace innovation system was well embedded in the national innovation system of Singapore. This not only offered synergies for the emerging industries, but was the main reason why Singapore managed to respond to competitive challenges quickly and avoided decline of production that lasted more than a year.

Figure 4.23 Radical innovation system change in Singapore’s sectoral innovation system in Aerospace



(Author’s compilation)

As shown in Figure 4.23, a radical innovation system change occurred between 1989 and 1992. This shift coincided with a global crisis in the aerospace industry, which was triggered by the decrease in defence spending and increase in oil prices at the end of the Cold War and beginning of the Gulf War. Singapore was one of the first countries to readjust its innovation system and industrial orientation according to the changed competitive environment It quickly realized the advantages it can gain from the internationalization of supply chains and the dismantling of previously vertically

[146] Immigrant labor was an overall important knowledge source for Singapore. Immigrant stock increased from half a million in 1980 to 1.5 million in 2005; also relative share in society increased from 22% to 35% (World Development Indicators Online).

DOI: 10.14267/phd.2016013

integrated company structures in Europe and North America. Singapore had a potential to become a low-cost regional supply and maintenance base, but only if it could expand the capacities (gaining economies of scale by expanding internationally) and by increasing its portfolio of design and production capabilities. Joint development only occurred in the case of the EC-120 helicopter project, but Singapore remains a potential location for components development, given the continued investment in R&D (two-third of which is paid by the private sector) and in physical and human capital. On the other hand, economies of Asia were demonstrating rapid growth which offered potentials for the aviation industry and supporting manufacturing and MRO bases. To make the state-owned companies more flexible for international expansion and raise capital, the government chose partial flotation in the case of ST Aerospace, or spinning off the Engineering Division of SIA. (Note the similar considerations behind the privatization of Embraer). Because of responding quickly to the new competitive environment, Singapore's aerospace industry has managed to maintain a competitive edge in the rapidly growing region, despite existing and emerging competition in Hong Kong, Thailand and Malaysia.

Unlike any other emerging aerospace producer country, Singapore successfully managed a 'transition without interruption' in the sectoral innovation system. It was a fundamental system change in which Singapore was targeting the knowledge-intensive activities within the industry. This is indicated on the one hand by the two-fold expansion of R&D expenditure and number of science and engineering researchers in the national innovation system between 1990 and 1995.[147] On the other hand, it is indicated by the changing product structure of the aerospace manufacturing industry (MRO and small parts and components manufacturing of the latest aircraft models; avionics and engine components manufacturing and a declining share of military programs). The number of new aerospace firms in Singapore increased after 1990, but so did the largest Singaporean MRO firms expand in foreign markets.

Singapore also succeeded in managing the transition efficiently. The aim and means of achieving competitiveness were well designed in the emerging innovation system, which minimized institutional inertia in a time of transition. For instance, the product structure and repair activities did not have the long lead time which aircraft producers

[147] There is no consistent data to monitor aerospace R&D and innovation measures over time. *The National Survey of R&D* by A-Star has a changing coverage of firms between 2002 and 2009, in the period available. We therefore rely on indicators for the whole economy.

DOI: 10.14267/phd.2016013

had to deal with. The similarity between existing capabilities and those required in the new system was high and highly compatible. What companies had to learn was organizational innovation, in addition to a rapidly developing avionics segment and a rather incrementally changing engine or aircraft parts production and repair activities. Moreover, the innovation system has had a number of actors specialized in fostering knowledge exchange, such as the Association of Aerospace Industries in Singapore, private consultants or government funded R&D agencies. In addition, a sound macroeconomic environment and high economic growth[148] were similarly important for a swift transition.

In the coming decades, the Asia-Pacific region is forecast to witness further rapid growth in air traffic. Singapore's challenge will be to sustain their first-mover advantage as many other countries in the region will compete to become MRO hubs. Large investments were made in MRO in Thailand, Malaysia, as well as in China. So far Singapore has successfully safeguarded its position (and retained budget airline clients as well) against cheaper locations in neighboring Johor Bahru or Kuala Lumpur in Malaysia based on its reputation of top-quality service and guaranteed, rapid turn-around time owing to the efficient organization of engineering and management of logistics. Even if neighbors can catch up with the services over time, the incomparable performance and investment into the national innovation system of Singapore will most likely continue to offer the required linkages to respond to find a new competitive edge.

[148] Between 1989 and 1992, annual GDP growth averaged at 8%.

DOI: 10.14267/phd.2016013

4.5 ARGENTINA: The case of a languishing aerospace innovation system

4.5.1 Introduction

Despite a very promising start, a fully functioning aerospace innovation system never emerged in Argentina. Local aircraft design and construction activities started before World War II in Córdoba where an advanced plant employed over 9000 employees by 1950.[149] However, it was a military plant and export considerations played little role in new product development. The inward-looking economic strategy soon proved to be unsustainable, creating a crisis in a still infant industry. In the absence of a transition to a different growth trajectory, the industry languished. Subsequent efforts in the 1960s and 1970s by military governments to pump more money in an unchanged innovation and production system once again resulted in a short-lived success. Technological capabilities continued to erode. Attempts at privatization in 1987 and concessions in 1995 were not combined with well-designed, radical institutional changes. As a consequence only around 1000 employees work in the aerospace industry, which does not mean more than maintenance and overhaul activities in Córdoba.

In 1969, when Embraer started, Argentina had the largest aircraft industry in Latin America in terms of employees (value added is not known). By 2003 value added was 70 million USD, equal to less than 3% of Brazilian value added (Table 4.7).

Table 4.7 Argentina's Aerospace production in comparison, selected years (USD mln at constant = 2000 prices)

Country	1984	1993	2003
Argentina	40	9	70
Brazil	242	260	2,581
China	3,599	1,692	3,392
Indonesia	12	192	n/a
USA	48,281	53,218	47,949

Source: Argentina: UNIDO (for years 1984, 1993) and INDEC (2003); Brazil: IBGE; Chile, Colombia: UNIDO. *Note:* PPP/UVR applied for conversion of local currency to USD: Argentina: 0.846; Brazil: 1.09; China: 4.6; Indonesia 4201. (See Chapter 3 for UVRs).

Since its founding in 1927, the plant giving home to aerospace manufacturing and related activities in Córdoba has often changed its name, internal organizational

[149] The sources on Argentina can at best be called patchy. Production statistics are almost non-existent. Hira and Oliveira note that "there is no documentation regarding audits or financial reports to be found regarding the Fábrica; no systemic evaluation appears to have taken place" (2007 p.344). Limited national statistics on the sector at 3-digit level are only available for the years 1983, 1994 and 2003. We therefore rely on secondary literature, including industry journals (e.g. various editions of *Flight International*), the Chronicles of the Ministry of Science and Technology of the Province of Córdoba (Arreguez 2007) and the insightful comparative analysis of Hira and Oliveira (2007).

DOI: 10.14267/phd.2016013

structure and external dependence. Table 4.8 provides an overview of the changes in scale and name.

Table 4.8 Name and size changes of the aircraft manufacturing plant of Córdoba

Year	Name of Organization (Abbreviation)		Number of Employees	Construction Floor (m^2)
1927	Fabrica Militar de Aviones	(FMA)	193	8,340
1931		(FMA)	n/a	34,000
1943	Istituto Aerotécnico	(IAe)	3,070	265,000
1952	Industrias Aeronáuticas y Mécanicas del	(IAME	9,550	n/a
1957	Dirección Nacional de Fabricaciones e	(DINFI	8,273	217,000
1967	Fabrica Militar de Aviones	(FMA)	n/a	n/a
1968	Area de Material Córdoba	(AMC)	7,507	n/a
1987	Fábrica Argentina de Materiales	(FAM	~3,000[a]	n/a
1991	Area de Material Córdoba	(AMC)	n/a	n/a
		(AMC)	2,200	n/a
1995	Lockheed Martin Aircraft Argentina S.A.	(LMA	1,250	~220,000
2002		(LMA	900	n/a
2010	Fabrica Argentina de Aviones	(FAde	1,100	~220,000

Source: Own compilation based on Arreguez (2007); Arroyo (2004) various articles of *Flight International*

Notes: (a) Estimate based on 1985 UNIDO figure of 3,092 for the entire aerospace industry;
(b)before privatization. Note that sources differ on the actual number of employees reduced over the privatization period. Scheetz (2002) reports that "the plant's 2950 workers were immediately reduced to 1950 (and then to 950)", whereas LMAASA director Radcliffe reports a reduction of workforce from around 2200 to 1250 when Lockheed Martin took over operations[150].

4.5.2 The emergence of a sectoral aerospace innovation and production system in Argentina

4.5.2.1 The emergence of aircraft manufacturing in Córdoba

The Fábrica Militar de Aviones (FMA, Military Aircraft Factory) was established in Córdoba in 1927,[151] more than 700 kilometers northwest of Buenos Aires. The plant was and Army depot under the supervision of the War Ministry. Operations began with 193 workers on a construction floor of 8,340 m^2. The following year the complex was expanded with a number of laboratories, workshops and auxiliary buildings. Initial production of small planes under license (e.g. the Avro K-504 *Gosport*, Bristol F.2B, Dewoitine D-21 or the Focke-Wulf FW-44 *Stieglitz*) was soon complemented with local designs. The first one was the AE C-1 *Triplaza* biplane from 1931. Other notable designs include the 5-seater transport plane AE T-1 from 1932, some 61 military observer monoplanes AE MO1 and the FMA 20 *El Boyero* (see Table 4.9). Licenses

[150] "Pampa production could roll again" *Flight International* 20-26 Mar 1996

[151] A few smaller, private workshops constructing simple aircraft had already been operating in Argentina since 1910, but the scale of their industrial activities were less significant compared to the one established in Córdoba.

DOI: 10.14267/phd.2016013

were acquired by FMA to locally produce engine designs of Lorraine Dietrich, Wright and Siemens. This provided the know-how to develop the Ae R-16 *El Gaucho* and I.Ae R-19 *El Indio* engines.

By the end of World War II FMA had produced around 400 planes (Table 4.9), about half of the Brazilian production in the same period. In both countries the military was the main user of locally made planes. But while Brazil was producing for the allies, Argentina declared itself neutral during most of the war. Argentina was therefore not receiving post-war aid and cheap supply of aircraft from the USA, which, ironically, meant that its aircraft industry did not experience the post-war crisis that affected Brazil until 1960.[152] Fueled by the isolationist economic and foreign policies of President Perón, the aircraft industry was designated as strategic and was given high priority even after the war.

Already in 1943 FMA was renamed as 'Instituto Aerotécnico' (Aero-technical Institute, IAe), with a mission to develop aeronautical production in Argentina and unite the related industrial activities, deemed strategic for national defense. The institute combined research, design, production and maintenance work. Army major San Martin became the director of I.Ae. At the same time there were significant infrastructural developments, including the addition of a new 20,700 m^2 assembly hall (the largest so far in South America).

A first local product of this techno-nationalist period was the IAe 22 *D.L.*[153], a trainer inspired by the North American T-6 *Texan*. By 1950, this was the most produced plane in Argentina. Between 1944 and 1950 two batches of 100 IAe 22 *D.L.* planes were delivered. The 22 *D.L.* used parts and materials produced domestically. The number of private companies supplying the aeronautical industry increased from 5 in 1941 to over 100 by 1945, as a result of a new boost to increase public-private linkages (Arreguez, 2007). In 1946 the first bomber in Latin America flew for the first time, the twin-engine IAe 24 *Calquin* (Royal Eagle), of which the military procured a series of 100.

[152] Although other sectors, especially the agriculture, did experience detrimental effects of Argentina being left out of the Marshall Plan and the loss of North American and European markets.
[153] D.L. stands for "Dientes de León", or lion's teeth, in response to US Secretary of State Cordell Hull's earlier reference to Argentina as a "toothless lion".

DOI: 10.14267/phd.2016013

Table 4.9 Serial Aircraft Production in Argentina

Aircraft Model	Type	Engine	First Flight[a]	Nr. built	Series Production	Notes
Local Designs[b]						
AE MO1	Military observer	Piston (Wright)	1934	61	(1934–37)	First local design produced in series
AE C 3	Two-seater monoplane	(Piston, Armstrong Siddeley)	1934	16	(1934–?)	
FMA 20 'El Boyero'	General Aviation	Piston (Continental)	1940	131	(1949–51)	Designed by FMA, produced by Petrolini Hermanos
I.Ae. 22 D.L.	Trainer	Piston (IAe and Hamilton Standard)	1944	200	(1944–50)	
I.Ae.24 *Calquin*	Attack/Light Bomber	Piston (Pratt & Whitney)	1946	101	(1947–50)	
IA 35 *Huanquero*	Multi-purpose aircraft	Twin-Piston (IAe)	1953	47	(1957–62)	Designed by Kurt Tank
IA 46 *Ranquel*	General Aviation	Piston (Lycoming)	1957	220	(1958–?)	
IA 50 *Guarani II*	Utility	Twin-Turboprop, (Turbomeca)	1963	48	(1966–?)	Seats 12 passengers
IA 58 *Pucará*	Ground attack and counter-insurgency	Twin-Turboprop, (Garrett, Turbomeca)	1969	106	(1974–86)	The only "exported" model
IA 63 *Pampa*	Advanced trainer, light attack	Turbofan (Garrett)	1984	24	(1988–90, 2006–07)	
Produced under license						
K-504 Avro *Gosport*	Biplane	Piston (Gnome, Rhone)	(1926)	33	(1928–?)	
Bristol F.2B	Biplane	Piston (Hispano S.)	(1916)	12	(1930–?)	
Dewoitine D 21	Monoplane	Piston (Armstrong Siddeley)	(1925)	32	(1930–?)	
FW-44 *Stieglitz*	Biplane trainer	Piston (Siemens)	(1932)	190	(1937–?)	Licence acquired in 1937
Curtiss *Hawk* 75	Fighter	Piston (Wright)	(1935)	21	(1940–?)	Manufactured entirely at FMA. Licence originally acquired for 200 planes, but lacked material to complete.
Beech T-34 *Mentor*	Trainer	Piston (Pratt & Whitney)	(1948)	75	(1957–65)	Designed by Beechcraft, produced from kits
MS-760	Jet trainer	Twin-Turbojet (Turbomeca)	(1954)	36	(1958–64)	Designed by Morane-Saulnier, produced from kits
Cessna-182	General Aviation	Piston (Continental)	(1956)	40	(1969–72)	Designed by Cessna, produced from kits
Locally Converted						
A-4AR *Fightinghawk*	Ground attack	Turbojet (Pratt & Whitney)	(1954)	28	(1997–2000)	A-4M 'Skyhawk II' modernized in Argentina with US components; additional 8 modernized in the US

Sources: own compilation based on information from Arreguez (2007); SIPRI and Jane's.
Note: (a) First flight in brackets indicates the first flight of the original model; (b) The list excludes models of which only a few prototypes were built.

Migrant European aircraft designers (originating in Germany) during and after the war were important sources of technological expertise for both Argentina and Brazil. A team under the supervision of Emile Dewoitine designed and built the IAe-27 *Pulqui* (Arrow) jet fighter which successfully accomplished its maiden flight in 1947. Although only one prototype was built of this rather peculiar design, it was a major milestone that made Argentina the fifth country in the world (and the first in Latin America) to

DOI: 10.14267/phd.2016013

construct a turbojet fighter. In 1947 the former technical director of the German Focke-Wulf aircraft manufacturing company, Kurt W. Tank and his team of some 60 engineers were invited by Perón to work at Córdoba.[154] The team developed a new jet fighter, the IAe-33 *Pulqui II* (first flight 1950). This was a highly advanced fighter, matching capabilities with the Soviet Mig-15 and the American F-86 *Sabres*. The design and adjustment of the technology took several years, and by the end of 1956 the first four prototypes crashed or were damaged beyond repair. The air force showed interest to procure of the *Pulqui II*s even after the regime change following 1955. But the project continued at a very slow pace once its German designers left and the aircraft industry lost political support. Eventually the project was discontinued and the fifth prototype was parked in a museum in 1960 when the government chose to import the F-86 *Sabre* fighters from the USA.

The failure of the *Pulqui II* project had technological as well as political reasons. On the one hand the design was well beyond the level of existing local technological capabilities. Tank's team worked in a virtual enclave and the German team made little if any efforts to integrate the local workforce and to facilitate learning-by-doing. In this respect the project was more an offshoot of the WWII German innovation system than a product of Argentinean innovation system. It did little to advance the latter (apart from possible inspiration of future scientists through demonstration effects). On the other hand the project depended on Perón himself and the success of the Peronist economic and foreign policies. The industrialization strategy focusing on the domestic market failed after a short-lived post-war success, demand for intermediate imports skyrocketed and the economy found itself in stagflation (Della Paolera and Taylor 2003). Even before the "Liberating Revolution" ousted Perón it became apparent many of the extravagant projects (including the nuclear endeavor and the jet fighter) were not sustainable. Increased pressure from the USA following the revolution also contributed to bringing the projects to a standstill.

Despite the growing demand for air transport services, the design and production of aircraft in Argentina was *only destined for military use*. Following the first air postal

[154] This fits in Perón's strategy of acquiring former German (Third Reich) expertise to boost the development of the "New Argentina". Together with Tank came for instance Ronald Richter, a nuclear physicist of Austrian origin with the promise to be the first to produce nuclear fusion in the world. Perón gave Richter virtually unlimited resources to develop the technology for a new energy source (and potentially for a nuclear weapon) in the 'Huemol Project'.

DOI: 10.14267/phd.2016013

services[155], passenger air routes were established in the 1930s. The joint stock companies of regional airlines formed in the 1930s, were nationalized in 1949 and merged into the new Aerolíneas Argentinas (AR). In 1956 the new government broke up the monopoly but AR remained the dominant airline (also becoming the largest airline in South America), with Austral as its most significant domestic competitor. Supplying AR or Austral by locally made planes was never a real option for FMA or its successors. The primary goal was supplying and maintaining the Air Force fleet.

Table 4.10 Stock of aeronautical engineers in Argentina (1950-2007)

	cumulative nr. of university graduates in aeronautical engineering			**Estimate of active stock[a]**
Year	**UNLP**	**IUA**	**Total**	
1950	18	14	32	32
1955	54	76	130	130
1960	59	136	195	195
1965	86	165	251	251
1970	142	197	339	339
1975	218	239	457	457
1980	275	277	552	552
1985	343	336	679	647
1990	472	392	864	734
1995	614	425	1,039	844
2000	727	473	1,200	949
2005	821	554	1,375	1,036
2007	866	584	1,450	1,068

Sources: Instituto Universitario Aeronáutico (IUA), Departamento Egresados, Universidad Nacional de La Plata (UNLP), *Lista de egresados en nuestra base de datos*.
Note: a) active stock is estimated by assuming 35 years of active career for a graduate.

The military ownership of the aeronautical industry is also reflected in the *education and training* of future labor force. The Air Force operated pilot training schools. The initially ad-hoc training of engineers and workers of the industry was replaced in 1941 by regular theoretical and practical courses in aeronautics. The Escuela de Ingeniería Aeronáutica (Aeronautical Engineering School)[156] was established in 1947 in Córdoba under the supervision of the Argentinean Air Force. The most important non-military graduate training center for aeronautical engineers was the Engineering Faculty at the Universidad Nacional de La Plata near Buenos Aires. As shown in Table 4.10, the number of graduates was very low, creating an obvious bottleneck for the emerging innovation system. Although 864 engineers were trained by 1990, by comparison, in Brazil over 3000 engineers graduated from ITA alone until 1988.

[155] The perils of aviation in Argentina in the 1920s and 30s are illustrated by Antoine de Saint-Exupéry in his 1931 novel *Night Flight*.
[156] It was renamed in 1993 as Instituto Universitario Aeronáutico (University Institute of Aeronautics, IUA).

DOI: 10.14267/phd.2016013

A *research and testing* center was already established under the War Ministry during the late 1920s, with its mission encompassing the design, development and construction of various prototypes of aircraft, engines and instruments. R&D was subsequently incorporated into FMA and its successors.

4.5.2.2 Incomplete emergence (1927-1952)

Even with the scant statistical data about the early growth of the industry, the contours (and the deficiencies) of an emerging innovation system are apparent. It never functioned properly as a fully developed system, as the following overview of its main building blocks during the period of 1927-1952 reveals:

1. **Actors:** The most striking feature of the emerging innovation system is the absence of private companies. Research, design, engineering and production, but also education and training were all "integrated" in the military complex at Córdoba. The Argentine Air Force oversaw the plant, financed its research and production activities and appointed the managers. Tank and his team, a potentially rich source of foreign expertise, had very little interaction with the rest of the actors in the system. Even though they were located at FMA, they were supported by and reporting directly to the president.
2. **Institutional set-up:** Ever since its origins, FMA and its successors were run as a military unit. Technological independence (following the import-substitution strategy) and increasing Argentina's military capabilities were the prevalent objectives, not commercial success. This did not prove to provide successful incentives for innovation. External relations of the system were determined by the current governmental strategy, including the degree openness to foreign technology and the selection of technological partners (orientation shifted from the British to the Axis powers during the war). Internal relations were cloaked in secrecy, which greatly reduced the potential of establishing linkages with other domestic or foreign industries. It reinforced the hurdle to commercialization of technological results.
3. **Capital input:** Lack of rigorous accounting makes it impossible to trace the amounts invested in development projects. It is only clear that innovative activities were financed by the government – as in all other emerging innovation systems –, although these were determined by political aims rather than economic ones. The lack of financial transparency ensured a culture of corruption already from the very beginning.

DOI: 10.14267/phd.2016013

4. **Technology base and input:** At the time of the establishment of FMA in 1927, technological capabilities in aircraft construction and maintenance were existent although very limited. It is worth noting that the related automotive manufacturing industry was already present in the country with models of leading foreign producers being assembled under license.[157] Similarly in the aircraft industry production licenses of small planes (e.g. Avro, Bristol, Dewoitine, Focke Wulf, Curtiss and Beechcraft) provided access to foreign technology. After WWII European designers (such Dewoitine and Kurt W. Tank and his team) brought along not only their knowledge and skills but also blueprints of new aircraft. These frontier technologies were incompatible with existing local knowledge and no serious measures were taken to help acquire the tacit knowledge. Technology deals were not signed strategically with capability accumulation in mind, but rather for short-term political purposes.
5. **Skilled labor input:** The labor force was almost exclusively trained by the academies of the military in Córdoba, first in ad-hoc training courses, later in regular engineering program. Shortly after the end of the war an aeronautical engineering school was established by the air force (see above) and civilian courses started at National University of La Plata. But the number of aeronautical engineering graduates did not reach 100 until 1954. As opposed to Brazil, the lack of a dedicated aerospace school (such as ITA) became a major shortcoming in the innovation system.

In the absence of statistical data, we can only indirectly deduce the performance of this emerging innovation system.

6. **New products:** Most of the new products before WWII were small planes carrying maximum five persons, capable of very simple, mostly observation missions or to be used for pilot training (Table 4.9). The *Pulqui I* and *II* jet fighters designed in the post-war era represented near-frontier technologies, but they remained inventions rather than innovations, as they never reached series production.
7. **Output and Market share:** We estimate that by the end of WWII Argentina had produced some 400 planes (see Table 4.9). However, none of them were sold outside Argentine or for domestic or foreign commercial use. We have no information on aircraft import before 1950s; when the military started to import

[157] By 1930 the Argentine car park amount to over 400,000.

DOI: 10.14267/phd.2016013

aircraft from the US during the late 1950s it considerably reduced the high market share of locally produced military planes.

4.5.3 Crisis in the Industry: Replacing wings with wheels

The initial rapid growth of the industry slowed down by 1950 and the industry was soon in a serious crisis. Import substitution with a domestic orientation meant that export revenues could not finance the purchase of foreign raw materials and intermediate inputs on which aircraft production and other industries depended. Trade deficits and lack of growth of manufacturing industries forced Perón's second government[158] to make major changes in industrial policy. The survival of the Argentinean aircraft manufacturing industry was in jeopardy. In order to save the Córdoba plant, San Martin, the head of the plant (and also the Minister of Aviation since 1951) agreed with Perón to diversify activities into automobiles (as well as tractors, motors, motorcycles and arms) production.[159] Resources devoted to aircraft design and production were significantly reduced as political discontent with the national aircraft endeavor increased, which was further aggravated by a growing macroeconomic crisis.

In late 1955 Perón's government was overthrown in a coup. The following governments[160] aimed to reverse the major projects associated with Perón, including the aerospace endeavors. A large part of the military management was replaced and aircraft and automotive production activities were separated. Tank and his team abandoned work on the jet fighter and other experimental designs and left Argentina in the unwelcoming political climate after the dismissal of Perón.[161]

The car and aircraft industry of Córdoba was soon formally separated. In 1957 the automotive industry was transferred to a separate organization, and aeronautical research and production activities were reorganized in the Dirección Nacional de Fabricaciones e Investigaciones Aeronáuticas (National Directorate for Aeronautical Production and Research, DINFIA), which remained under the supervision of the Air Force. When established, DINFIA had 8,273 workers, a floor space of 217,000 m^2 and

[158] After 5 years in office, Perón was reelected in 1951.

[159] Perón was also seeking to supply cheaper, domestically made cars to offset the ever more expensive import and the reluctantly growing assembly work of foreign subsidiaries. By the end of 1953 some 2000 cars were produced by IAME. (FMA was renamed to Industrias Aeronáuticas y Mécanicas del Estado – h IAME, Aeronautical and Mechanical Industries of the State).

[160] The "Liberating Revolution" was followed by the military gaining control over the government. The first elected president was the right-wing Frondizi, still favored by the armed forces (1958-62).

[161] Tank himself went to India in where he designed a jet fighter-bomber, the *Marut* for Hindustan Aeronautics.

DOI: 10.14267/phd.2016013

3,500 machine tools in total of 19,500 horsepower. At the same time the Instituto de Investigación Aeronáutica y Espacial (Aeronautical and Astronautical Research Insitute, IIAE) was established and designated to carry out R&D activities in aerospace.[162]

However, neither the national governmental, nor DINFIA leadership had a consistent strategic vision on the development of the industry. Between 1955 and 1960 the organization had 9 directors and many parallel projects. The military decided to follow up on a design by Tank's team of which a first prototype was already flown in 1953. An order of a 100 planes was placed for the multi-purpose twin-engine propeller plane, the IA 35 *Hanquero*, but only 47 were eventually built from 1958 onwards.[163] At the same time the right-wing governments forged closer ties with the USAand signed deals to procure US trainers and fighters.[164] Many of the received trainers (such as the North American T-6 *Texan* or T-28 *Trojan*) and fighters (e.g. the North American F-86 Sabre, which Argentina received in the form of assistance) were in the same size range as the ones produced in Argentina (e.g. the IAe-22 *D.L.* or the IAe-33 *Pulqui II*), but the (older) US-made planes showed superior performance characteristics. The new foreign purchases were not coordinated with the strategies of domestic aircraft industry development and siphoned off much of the resources for procurement of locally-made planes. The innovative designs such as the *Pulqui II*s would have required more investment to be improved to a level that would be marketable abroad. New prototype development was largely discontinued. As there was no strategic aim to make Argentinean production competitive, the technological capabilities started to erode from the 1960s onwards.

4.5.4 Interruption without transition

4.5.4.1 The first interruption in the innovation system: the 1950s

The industry's crisis due to macroeconomic and political factors caused an interruption in the innovation system. The lost financial and political support of grand design projects were not replaced by other sources. Capabilities at the macro level eroded with the departure of the German engineers, even if they were less connected with the other

[162] Space research culminated in 26 rocket launches between 1961 and 1981.
[163] A number of derivatives made of this model, in the direction of a transport aircraft (e.g. the *Guarani I*, with a capacity to seat 11 persons). A successful plane from these years was the IA 46 *Ranquel*, a small utility plane used by aero-clubs and for agricultural purposes. (Table 4.9).
[164] The US government was suspicious of both the Argentinean nuclear and military aircraft development projects and was therefore rather willing to sign export deals if that meant an alternative to local plans.

DOI: 10.14267/phd.2016013

actors in the system,[165] and they were also not replaced. By this time the global industry was entering the jet age and the Argentinean innovation system's distance to the global technology frontier was increasing rapidly.

A radical transition would have been required,[166] but instead attempts were made to sustain the industry without major institutional changes. The industry and innovation system were still emerging and lacked many important actors, including private firms, educational and training institutes, but most importantly there was no development strategy combining industrial, science and technology and education policies. It follows that both the size of the innovation system (decreasing of technology and financial inputs) and the innovative performance system (very few new designs created) of the system declined.

The rest of the history of Argentinean aerospace industry shows how heavy a price the country paid for trying to patching a decaying innovation system.

4.5.5 Lack of strategic leadership

Argentina after Perón did not give up on aircraft manufacturing. An alternative to local design was to return to local manufacturing of foreign-designed planes. DINFIA acquired licenses from Beechcraft (US) to produce 75 propeller-driven T-34 *Mentor* trainers and from the French Morane-Saulnier to produce the MS-760 twin-jet trainers. A decade later Cessna (US) gave a license to AMC for 40 C-182s aircraft. However, the only local content in these activities was labor. All the components were shipped in kits from the USA and France. While in Brazil license-production activities over the 1960s and 1970s were part of a strategy to acquire specific know-how, Argentina lacked an overarching plan at the government level and lacked entrepreneurs at the firm level.

The difference between the history of the industry during the 1950s and 60s in Brazil and Argentina is striking. Brazil, although also with many often conflicting goals at that time, was making significant efforts to create the foundations of an aerospace innovation system in the Sao Jose dos Campos cluster. Argentina was conducting research into military aircraft design, produced a number of them, but made insufficient efforts to create an innovation system. The failure of the *Pulqui II* project proved that

---

[165] It is interesting to point out the differences between the Soviet engineers and technical staff leaving China after the Sino-Soviet Split in 1961 and Tank and his team Argentina: Argentinean technological capabilities were more advanced without the guests, but China made more efforts to reverse-engineer and regain the lost capabilities afterwards.

[166] Diversifying into the automobile industry was an interesting alternative, nonetheless a genuinely radical shift – maybe too radical –, but it did not concern the entire industry.

DOI: 10.14267/phd.2016013

the Córdoba plant had not succeeded in integrating foreign frontier technology, and only relatively simple aircraft were produced locally under license. Even this expertise was, however, already declining during the 1950s. In both countries the military was a major source of finance for education and R&D in aeronautics. While the sector was seen everywhere as strategic, neither country formulated a well-defined mission for the development of the industry.

Table 4.11 Military aircraft import to Argentina (1950-2009)

Types	Model	Year	Nr. planes	Exporter
Trainers	T-6 *Texan*	1956 1959	5 5	USA
	T-28 *Trojan*	1959-60:	45	USA
	T-28 *Fennec*	1966	45	France
	Aermacchi MB-326	1969-70 1983	8 11	Italy
	T-34C *Turbo Mentor*	1978	16	USA
	Aermacchi MB-339	1980	10	Italy
	EMB-312 *Tucano*	1987-88	30	Brazil
	Su-29	1997-98	8	Russia
Fighters	F-4U *Corsair*	1956-58:	62	USA (used in WWII, Korean War)
	F-9F *Panther*	1957-58:	20	USA
	F-86 *Sabre*	1960:	28	USA
	A-4P ground attack *Skyhawk*	1966-7 1970 1972 1976 1997	25 25 16 25 36	USA (28 of which modernized locally)
	Mirage	1972-3 1980 1983	12 7 2	France
	Nesher (=*Mirage* 5)	1978-82:	39	Israel
	Mirage 3	1982-83:	22	Israel
	Mirage-5s	1982:	10	from Peru (loan for Falklands war, later bought)
Bombers	Canberra B(I)-8 and -12	1970-71	12	UK
Transports	Shorts *Skyvan* SC-7	1971	5	UK
	F-27	1968-81	21	Netherlands
	C-130 *Hercules*	1968 1971-72 1975 1979 1992-94	3 3 2 2 5	USA (KC-130H tanker/transport)
	Alenia G-222	1977	3	Italy
	CASA C-212	1989-90	5	Spain

Source: SIPRI

DOI: 10.14267/phd.2016013

In Brazil a "public entrepreneur"[167] emerged to fill the gap of lack of strategic vision on commercialization. The reason why such a development did not happen in Argentina cannot be merely attributed to bad luck. The institutional framework of the Argentine aircraft innovation and production system did not allow the emergence of such an entrepreneur. First, the Argentinean aerospace "enterprise" was a military organization and not a company with commercial aims. It had no influential private actors with experience in commercializing the products. Second, the frequently changing governments were incapable of providing financial and political support for the infant industry. It was partly due the secretive nature of the military, but it was also in the culture of the public science and technology community to be more cautious with commercial valorization of applied technology.

Already by the 1960s DINFIA had cancelled the development of jet fighters and focused its activities on transport, counter-insurgency and training aircraft (Milenky 1980). In addition to the *Sabres* received in 1950, between 1966 and 76 the military governments of Argentina imported some 90 modernized Douglas A-4 *Skyhawk* ground attack jets in several batches, 8 C-130 *Hercules* transport planes in 3 batches and a number of small planes. But the US was not the only supplier. Argentina opted for French Mirage III fighter jets in 1970, and despite more ambitious plans 21 fighters were acquired between 1972 and 1983 in batches of 12+7+2. These were complemented with a 1978 deal with Israel on 26 refurbished IAI *Nesher* planes (which were largely identical to the French Mirage V jets, but equipped with Israeli avionics). (See Table 4.11 for an overview of imported aircraft.)

4.5.5.1 Renewed efforts to build up domestic technological capabilities in aerospace

In 1967 aerospace development and production activities were reorganized after a transition year into Area de Material Córdoba (AMC). The plant continued to be run by the Argentinean Air Force. Yet reorganization also meant renewed interest in boosting the industry's design output. There were significant technological achievements during between the 1960s and 1980s.

The IA 50 *Guarani II,* a small utility aircraft, seating 12 passengers was also capable of limited troop transport, medical and search and rescue operations. The prototype was based on Kurt Tank's IA 35 *Huanquero,* and first flew in 1963. Two years later The

[167] Using the term coined by Ramamurti (1987), however, referring to the team of aircraft engineers working on the design and marketing of the future Embraer *Bandeirante*.

DOI: 10.14267/phd.2016013

Guarani II was presented at the Paris Air Show. This could have been an aircraft for commercial use (and indeed after the first series of 18 built for the military between 1966 and 1970, a second series of 14 planes were constructed between 1971 and 1974 for the civilian market)[168]. According to the published specifications, the *Guarani II* outperformed aircraft in its league. It could fly higher, faster and further than Embraer's star product, the *Bandeirante* (see Table 4.12).

Table 4.12 Main features of the Guarani II in comparative perspective

	DINFIA IA 50 ***Guarani II***	**Embraer EMB-110** ***Bandeirante***	**CASA C-212** ***Aviocar***
Capacity (crew+passengers)	2+15	2+21	2+26
Dimensions (m): (length/wingspan/height)	14.9 / 19.5 / 5.81	15.1 / 15.4 / 4.9	15.2 / 19.0 / 6.3
Empty weight (kg)	3,924	3,500	3,700
Maximum takeoff weight (kg)	7,120	5,900	6,300
Power plant	2x694 kW Turbomeca Bastan VI-A Turboprop	2x559 kW P&W Canada PT6A-34 turboprop	2x580 kW Garrett AiResearch turboprop
Max speed (km/h)	500	460	370
cruise speed (km/h)	450	326	315
Range (km)	1,995	1,964	1,760
Service ceiling (m)	12,500	6,900	7,900
First Flight	1963	1968	1971
Total Number Built	35	500	435

Sources: Jane's, Aeromilitaria.Com.Ar, Airliners.Net

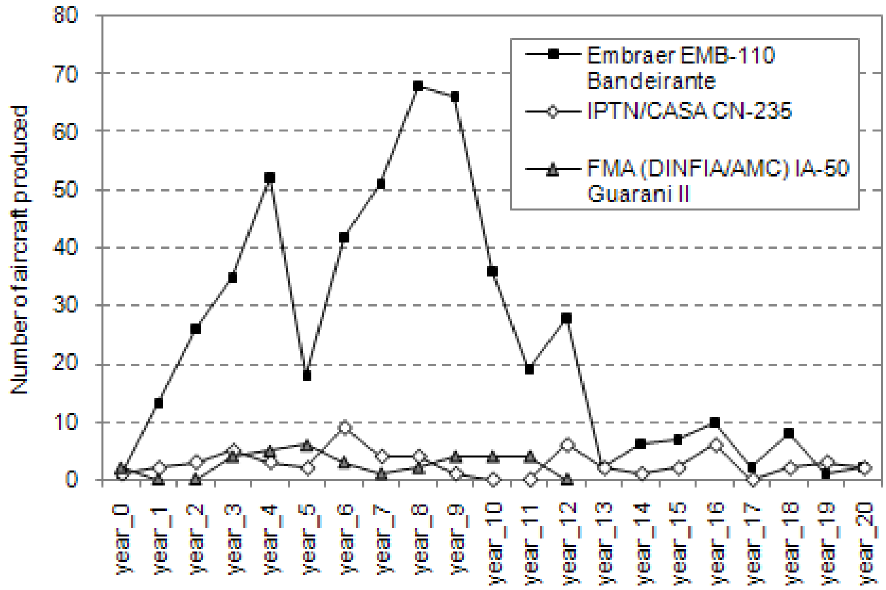
Puzzling as it may first seem, it is important to note that the aircraft was not responding to what commercial markets demanded. None of the 34 planes that are believed to have been built[169] were exported or sold to airlines. Most of them were used for aerial photography, calibration of navigation instruments and various transport services. Without sales revenues and with an aggravating economic crisis, production was not sustainable and Perón's new government stopped further support in 1974. Figure 4.24 shows the drastic difference in the production cycle of the *Guarani II* and the *Bandeirante*. This figure emphasizes the capacity of the newly emerging Brazilian producer to design an aircraft for commercial markets and construct it in great quantities, in contrast to the laggard position of its older Argentinean counterpart.

[168] Source: "Guaraní" *Aeromilitaria.Com.Ar*
URL: http://www.aeromilitaria.com.ar/ind/aviones/gii/index.htm (page last updated: 3 Mar 2007).
[169] The Argentinean Air Force reportedly used 29 of them, but little is known of the operating history of the plane. Aeromilitaria.Com.Ar

DOI: 10.14267/phd.2016013

Argentina showed more resemblance to the also emerging Indonesian plane maker, to be discussed in the next section of this chapter.

Figure 4.24 Comparison of annual production of commuter-size aircraft by FMA, Embraer and Nurtanio (first 20 years of production)

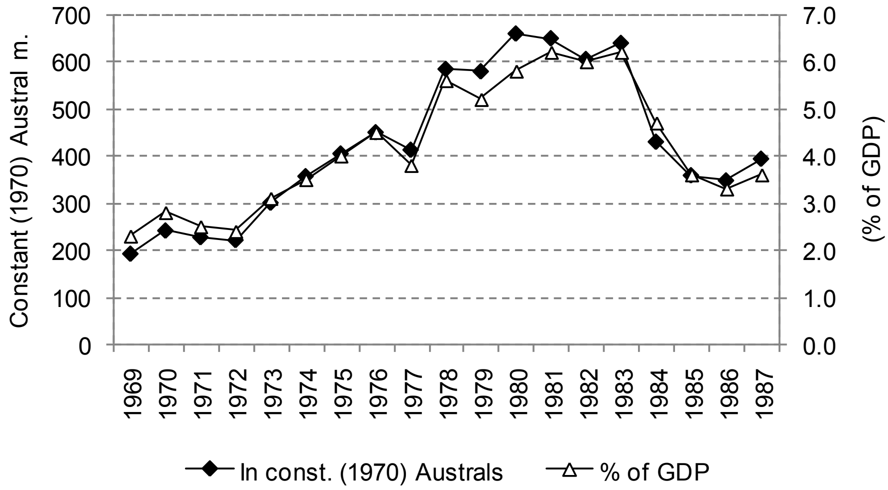


Source: Cabral 1987, Cassiolato *et al* 2002, Airlinerlist.Com, Aeromilitaria.Com.Ar
Note: The FMA and Embraer aircraft were designed and produced domestically. The CN-235 was co-designed and co-produced by CASA and IPTN; the figures presented show the number of aircraft finally assembled in Indonesia. The production of the IA-50 stopped in 1974.
Year 0 refers to the year of first flight of the prototype (EMB-110: 1969; CN-235: 1983; IA-50: 1963).

The zenith of the Argentine defense industries coincided with the military dictatorship of 1976-83 (Scheetz, 2002). It was a time of increased military spending amounting to as much as 6% of the GDP between 1981 and 83 (see Figure 4.25). Details of the expenditure are not known, but the air force evidently managed to corner a large share of these expenditures. First of all, it should be noted that the junta's increased military expenditures were unsustainable due to macroeconomic instability. Still the availability of new funds, had they been channeled into the innovation system, could have resulted in increased innovative performance of the aircraft industry. However, foreign procurement and corruption absorbed a large of the available budget. Over these years Argentina modernized its fleet with about 80 *Mirage* fighter jets (including the Israeli derivative *Nesher*) and a number of trainer and tanker aircraft (see Table 4.11).

DOI: 10.14267/phd.2016013

Figure 4.25 Argentine Military Expenditures, in millions of constant (1970) Australs (1969-1987)



Source: Scheetz (1992, Table I, p.186)

AMC in Córdoba was commissioned to produce a hundred of the IA-58 *Pucaras*. This two-seater twin-prop ground attack and counter-insurgency aircraft was first flown in 1969. Its main features were the capability to operate in unfavorable conditions, simple airfield infrastructure requirements and good maneuverability. But it was using already dated technology. 106 units were built between 1974 and 1986, and it was the only Argentine aircraft "exported", even though none of these exports were realized through regular market transactions.[170] Due to the limited availability of spare parts, the exported planes eventually did not clock many flying hours. Their capability to land and take-off on short runways made the *Pucara* the only aircraft the Argentinean Air Force could deploy to the Falkland Islands during the 1982 war, where they carried out reconnaissance and light-attack operations. However, the Air Force's national technological pride did not stand the test of war and many planes were soon written off.

The subsequent *Pampa* project was a technologically even more challenging venture rather successfully realized. Once again it became a victim of changing strategic vision and macroeconomic and political instabilities. As of 1978 AMC was looking for solutions to produce a new advanced jet trainer to replace the nearly 20 year-old locally assembled Morane-Saulnier MS-760s jets. Aiming to follow international standards (to

[170] SIPRI counts a total of 10 exported aircraft. Six were delivered to Uruguay in 1981 as part of a 6.5 million USD deal from the previous year. In 1992 Argentina signed a deal with Sri Lanka to the tune of 12.7 million dollars to deliver four aircraft over the following two years for counter-insurgency operations. Additionally, the Air Force offered 3 of its *Pucaras* in 1990 in the form of aid to assist anti-narcotics operations in Colombia and leased one for a year for Uruguay (Based on SIPRI Arms Transfer Database; values are expressed in constant 2000 USD, applying deflators of 0.54 for 1980 and 0.86 for 1992 (WDI). Note that industry insiders question many of the details of these deals.

DOI: 10.14267/phd.2016013

facilitate foreign sales) and expand existing expertise in license production, AMC signed a partnership agreement with the German manufacturer Dornier to assist aircraft development.[171] The resulting prototype of the IA-63 *Pampa* trainers showed many similarities to the Alpha Jet, but it was a simpler and more cost-efficient design, equipped with a single Garrett turbofan engine. By the time the plane first flew in 1984, the military junta has already fallen following the disasters of the lost Falklands War, the shrinking economy and the debt crisis.

4.5.5.2 An incrementally changed innovation system (1960s-1983)

The realization of the *Guarani II*, *Pucará* and *Pampa* projects marked the revival of the aerospace innovation system. Innovative performance increased with the accomplishment of complex engineering achievements. This raises a question. Was this performance caused by increased learning and interactions within a system defined by more or less the same actors and institutions? Or does it mark a transition to a new system?

In our interpretation the innovation system did not change radically. The main actors remained the same, even if some additional foreign sources of technology were added (but with less intensive and rather unidirectional interactions). The major arrangements in the industry were hardly modified. Whatever the name of the Córdoba plant was, it was still run by the military. The system continued to be serving the needs of the Air Force, and despite some weak attempts to realize foreign sales, economic considerations had little influence. Moreover, the long lead times of projects indicate that the system was still in its infancy, still not close to the performance frontier. Yet the technological characteristics of the products were matching (or even exceeding) those of other latecomers. What we can observe here is that increased inputs (finance) could boost learning and result in performance increase in an *incrementally* changed innovation system.

The problem with an only incrementally changed innovation system was that even if it reached the performance frontier through learning, it was not competitive anymore. It could still add to the accumulation of technological capabilities needed for an emerging

[171] Together with Dassault, Dornier had been producing the Alpha Jet since 1973 but the production run was nearing its end.

DOI: 10.14267/phd.2016013

industry, but those capabilities were already obsolete. That it was not sustainable any longer was not only proven by the economic crises, but also in combat.

4.5.6 Failure to radically change an ailing innovation system

4.5.6.1 A new crisis: the end of the military regime and struggles with privatization

In order to address the debts and respond to the pressures of the international monetary institutions, the Alfonsín government that rose to power in 1983 cut military expenditures and made an attempt to privatize AMC. Under the new name of Fábrica Argentina de Material Aeronáutico (Argentine Aeronautical Materials Factory, FAMA) 44% ownership was sold to a consortium of Aeritalia and 10% to Techint.

The Alfonsin government continued to see potential in military aerospace and gave support to both the *Pampas* as well as a new medium-range ballistic missile program, the *Condor II*[172]. AMC produced a first batch of 18 *Pampas* between 1988 and 1990. The actual design and adjustments made to this took place during times of economic trouble in the country. AMC could not secure any foreign sales, although it attempted to apply for trainer procurement competitions in the USA (in partnership with LTV), New Zealand and Australia. Especially in case of the US application, the chances of a foreign producer of trainers have always been very low. The already dated technology of the planes and the fact that the Argentinean government was unable to offer competitive export credits were certainly not making it a serious contender.

An overture to commercial production at the end of the 1980s was also not successful. FAMA and Embraer decided to co-produce a commuter aircraft, the CBA-123 *Vector*. This was a major step in a new direction for FAMA and it offered the potential of acquiring newer capabilities as well as Embraer's already established knowledge of how to market planes. However, the project did not become a success because production costs were too high, making the plane uncompetitive. Embraer criticized FAMA for not being able to deliver the required modules in time and according to quality expectations. Argentina also had difficulties in financing its one-third share of the estimated 300 million dollar development costs.[173] The government's hands were tied in the midst of monetary and fiscal troubles.

[172] It succeeded a 1970s ballistic missile program and was developed in close collaboration with Egypt and Iraq, as the Middle East was seen as its potential market. The project was halted by the Menem government in 1993 following pressure from the US.
[173] Two prototypes were made in 1990 but the project was cancelled due to insufficient market demand.

DOI: 10.14267/phd.2016013

The 1994 privatization of Embraer in Brazil offered a capital injection and new sources of dynamism for regional jet production. However, while the sectoral innovation system in which Embraer was embedded may have meant an external asset to potential investors, the lack of such a system in Argentina decreased the value of FAMA (or AMC) [174], which was hardly more than a military depot seen as a burden on the state. Unsurprisingly, the Menem government's new attempt to inject capital into AMC in 1995 was less successful than the privatization of Embraer. First, the local aircraft industry could not show any commercial success similar to what Embraer achieved with its commuter planes during the late 1970s and 80s. The latest trainers of AMC were at least a generation behind the technology frontier, and were yet to be promoted on low-cost markets. Second, the core competence of the "company" was in military aeronautics, Argentina's options for a potential investor were limited to a few global defense companies, which were also experiencing a downturn after the end of the Cold War. Finally, the main asset of AMC was its 2,200-strong skilled labor force, but whether they provided a solid base for lower cost production is doubtful. Hira and Oliveira (2007:342) mention a consultancy report that suggested half of the work force was "surplus to requirement".

An in-depth analysis of the political background of the negotiations and the interests of the various stakeholders is beyond the scope of this study. After lengthy negotiations Lockheed Martin (LM) won a 25-year concession to operate the Córdoba aircraft factory, linked to a deal to upgrade 36 of the A-4 *Skyhawks* of the Air Force and to a promised 14 million dollars worth of investment.[175] Lockheed Martin Aircraft Argentina S.A. (LMAASA) assumed operations on 1 July 1995 and soon reduced the work force to 1,250. [176] Following the arrival of 8 A-4 *Skyhawks* upgraded in the USA, the first locally converted A-4s *Fighting-hawks* were delivered in 1998.

The government retained the right to renegotiate the deal every five years. While the signing of the original contract was widely criticized on grounds of corruption, incompetency or (at best) acting under pressure, the revision in 2000 expanded the responsibilities of LM and was financially more beneficial for the government as it was hedged against currency fluctuations. LMAASA now signed up to upgrade the IA-63

[174] The enterprise was once again renamed to AMC in 1991.
[175] Part of the deal was to seek to reactivate the manufacturing of the IA-63 *Pampa* jets and carry out maintenance and overhaul operations for both the Air Force and commercial airlines.
[176] "Lockheed nears AMC deal" *Flight International* 19-25 October 1994; "Pampa production could roll again" *Flight International* 20-26 Mar 1996, p.9. A different source on the number of employees, Scheetz (2002) reports a decrease from 2,950 to 950 (See note (a) to Table 4.8).

DOI: 10.14267/phd.2016013

Pampas and produce 12 additional aircraft[177] and carry out the maintenance of the Air Force's fleet and produce spare parts. Maintenance, repair and overhaul (MRO) became the core activities of the Córdoba plant, which also offered the potential to serve airlines in the region. But the diversification to the commercial segment was not so successful, mainly because of the poorer performance of local airlines.[178] Manufacturing remained a small scale activity, with no new aircraft designs. Lockheed indicated that it was expecting a domestic launch order of at least 100 *Pampas* to make use of scale economies, but the government (tackling a financial crisis) was struggling to meet their existing commitments.[179] The concession-adventure ended in 2009 as the Kirchner government nationalized the plant. Fabrica Argentina de Aviones (Argentinean Aircraft Factory, FAdeA), according to the new name, is once again subordinated to the Defense Ministry and there is little sign of any new strategy[180], new management routines or greater transparency.

4.5.6.2 Failed transitions to a more open innovation system (after 1983)

In 1983, with the lost war, the fall of the military dictatorship and a macroeconomic crisis, yet a second interruption hit the (emerging) innovation system. Military expenditures and AMC's labor force were halved and no new foreign technological collaboration deals were signed. But the Air Force continued to be influential even during the Alfonsín government so the *Condor II* and *Pampa* projects were not shelved.

The attempt to introduce private capital in the newly formed FAMA could have initiated major changes leading to a transition. However, basic incentive structures and selection processes were hardly modified. Private firm actors were still not significantly present, education and training institutions were not reinforced and no long-term industrial policies were devised in concert with innovation and science and technology policies to make the industry competitive. FAMA's entering into commercial

[177] Test flights of the *Pampas* with enhanced avionics and radar began in July 2005; the first delivery took place in December 2005 ("Upgraded Pampa trainer begins flight-test work" *Flight International* 12 Jul 2005; "Lockheed Martin advances Pampa push in Argentina" *Flight International* 11 Apr 2006)

[178] LMAASA had around 58,000 m^2 floor space for MRO activities in Cordoba. It has gained type certificates for a number of planes, including the C-130 *Hercules* and Aerolineas Argentinas' B-737s, as well as ISO 9001 from TÜV. The local workers accumulated experience in the repair works of the F-27, F-28, IA 50 G II, IA 58 and IA 63 types of the Air Force as well as in engines.

[179] For instance, in October 2003 LMAASA sent home its entire 900-strong staff for 6 days to reduce losses; at the same time, the government owed the company 47 million USD.

[180] The activities of the plant still include providing maintenance services for the Air Force's fleet (amounting to about half of the revenues), upgrading the *Pucuras* and making new efforts sell the *Pampas*. At the same time the air force's entire fleet is aging: only a small share of the fleet was active in 2007 and some 15 planes crashed in recent years. There have been plans to develop a new trainer to replace the ancient T-34s.

DOI: 10.14267/phd.2016013

production was not viable without such broader-scale changes, but Argentina could not afford these (especially in the context of neoliberal policies it was obliged to follow). Only incremental institutional changes took place. But at the same time, mostly due to insufficient funding, these were not followed by increased learning or a movement closer to the performance frontier. Thus, the macroeconomic changes at the end of the 1980s and the failure of the CBA-123 *Vector* project also mark an interruption in the innovation system, since the inflow of R&D funds and new technology from partners was significantly reduced. What remained after the break was an innovation system serving an industry with a “core competence” in maintenance, repair and overhaul (of both military and commercial aircraft).

The 1995 concession deal with Lockheed Martin has stopped further decline, but did not bring system-wide institutional changes. It provided access to technology, but hardly more than earlier license agreements; and it did not even secure capital investment for technological upgrading. These were improved with the renegotiated deal of 2000, which resulted in some increase in system performance. The 2009 renationalization was once again not a trend break for there is no sign of realigning the industry on a competitive growth path.

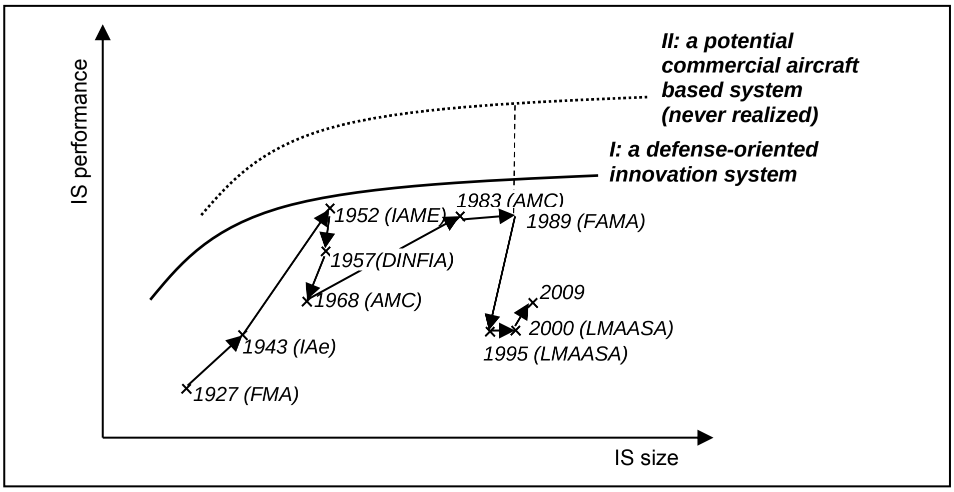
4.5.7 Interrupted innovation in Argentina: The rise and fall of an innovation system

This historical overview shows that a fully-fledged sectoral innovation system in aerospace has never emerged in Argentina, in a sense of supporting competitiveness and sustained growth. In the 70 years of its evolution there have been some periods of increased innovative activities, with tangible results of technologically complex new products, but no commercial breakthroughs.

A summary of the development trajectory of the innovation system is shown in Figure 4.26. The emergence of the system was interrupted in 1952 because import substitution with a domestic orientation caused a macroeconomic and later a political crisis. Yet there has been no transition to a new growth path, based on a strategy of export-orientation and the involvement of actors other than the military, most importantly, private companies. More investment pumped into an incrementally changed system proved to be unsustainable and led to new crises and other interruptions after the failure to enter into commercial production.

DOI: 10.14267/phd.2016013

Figure 4.26 The Emergence of the Argentine Aerospace innovation system



(Author's compilation)
Note: The abbreviations in brackets indicate the name of the main organization.

4.5.7.1 General conclusions

Although the ideas of 1927 envisaged the construction of a factory with the long-term aim of making it an engine of industrial progress in Argentina, much of the history of aerospace in Argentina is the outcome of ad hoc and short-sighted decisions. Formulating and adhering to a strategy of what to make locally and what to import is just as urgently needed as it has always been since the 1950s and 60s. In the end, it is too costly to keep supporting an infant beyond the age of 50. The following lessons can be derived from the Argentinean experience.

1. Nascent innovation systems are excessively vulnerable to exogenous shocks

Since the accumulation of technological capabilities has remained insufficient to design, produce and commercialize aircraft in Argentina, interruptions are results of events occurring in the macroeconomic or political context. This is especially typical of systems in their infancy, where the performance is excessively dependent on one source of finance and technology. (An example of such an interruption was the nascent Chinese aerospace industry after the Sino-Soviet split.) The reason is the lack of available institutions and actors to counterbalance the declines in government support. In conclusion, macroeconomic stability is crucial to provide a sustainable and credible source of government finance, political stability and a wide-spread agreement (possibly across party lines) is required to formulate and implement a long-term development strategy. Without such checks and balances the industry can still grow, but only slowly,

DOI: 10.14267/phd.2016013

at high cost and it can easily become a playground for short-term rent-seeking and power struggles.

2. Make competitive planes or do not make planes at all

Argentina never had a strategy to sell its products on the market (domestic or foreign). If the aim is to produce only for domestic military use, importing planes would have been a less costly option, creating a maintenance, repair and overhaul facility only would have been more lucrative.

After the ill-fated *Pulqui* fighter jet, the planes built in Córdoba were all of obsolete technology. All the planes Argentina imported or produced under foreign license were also near the end of their production runs. Although such planes are more affordable for domestic purposes, if the aim is to acquire the technology to produce planes that sell even on low-cost markets, a country can't afford not to invest in acquiring more recent technological vintages.

Even an emerging industry needs to pay special attention to what products and technological solutions are required by the market (domestic and foreign users), and to identify possible niches. It is too late to try to sell the obsolete *Pampa* trainers in the 21st century.

The argument that the presence of a high-tech industry boosts science and engineering education is shaky. The far-from-frontier knowledge and skills of the staff makes them less competitive even when they shift to other sectors, while the low payment (Scheetz 2002) deters new students from choosing a career in aerospace.

3. A military-only innovation system is bound to fail

The emergence of an innovation system will be unsuccessful if all the sources of technology and knowledge, all the interactions are controlled by the military. Channeling in investment and technology from private sources ensures not only more transparency, but also a more dynamic circulation of ideas. It also helps increase the number of actors in the innovation system who can better read the more complex signals of market demand than the air force decision makers alone.

Conversely, the number of new aircraft designs during the post-WWII years indicates a superior performance of an innovation system that is open to new actors (such as experienced foreign designers). However, the centralization of the selection process of new designs by the military hampers further growth in innovative performance. These routines and practices also hamper the ability to shift to commercial

DOI: 10.14267/phd.2016013

designs and the output of aircraft with potential commercial applications will be inferior to that of a genuinely commercially oriented firm (see Figure 4.24).

4. An emerging innovation system and industry require institutional stability and long-term goals

A lack of overall agreement on the strategies of policies related to industrial development, science, technology and innovation, or national defense by the main political actors of a country is a source of institutional instability and turbulence. The lack of institutional stability undermines the accumulation of technological capabilities, and innovative performance cannot increase even during the emergence phase. Goals and strategies that depend on solely on state financing are worthless if new governments easily cancel the commitments taken on by their predecessors.

5. The 'lost decade' in aerospace was the 1950s

For Argentina, the 1980s are generally referred to as the 'lost decade'. For the aerospace industry in Argentina, the decade of lost opportunities was the 1950s. Apart from the first Perón government, the industry never received sufficient resources and attention to allow it to reach a mature, competitive growth trajectory based on commercial sales. The distance to the technological frontier appears to have been growing ever since.

The attempt to close the gap during the late 1970s and early 1980s was overshadowed by the Falklands war and the debt crisis. Even if entrepreneurs had the foresight to make the crisis-hit industry ride the waves of the just emerging global trend of outsourcing components manufacturing by US and European producers to low-cost countries, the macroeconomic conditions of Argentina and the insufficient capabilities (that became clear during the CBA-123 *Vector* project) would have posed too big a challenge.

In other words, the case of Argentina shows that without a radical innovation system transition the aircraft industry can only survive on a lifeline. At such a low performance many more decades are being lost.

DOI: 10.14267/phd.2016013

4.6 INDONESIA

4.6.1 Introduction

In a country with a total area of 1.9 million square kilometers spread over 17,500 islands, the geographical setting itself makes the development of air transportation an obvious policy goal. Yet the development of the aircraft manufacturing industry would seem a less obvious choice for a developing country which was in the mid-1960s, according to Hill "perhaps the least industrialized of the world's large developing nations" (2000, p.155) and where natural resource-based industries accounted for 80% of total output (Hill 1990).

The overall purpose of focusing on aerospace among other high-tech industrialization projects was to accelerate the social and economic transformation of Indonesia from an agricultural to an industrial society. Dr. Bacharuddin Jusuf Habibie, the aeronautical engineer and later president of Indonesia summarized Indonesia's ambitious technology strategy in his famous phrase: "start from the end, end at the start". Accordingly, in 1976, IPTN, the state-owned aircraft manufacturing enterprise began to produce helicopters and airplanes under Western license. In less than half a decade it moved on to jointly develop a modified version of the plane, which successfully completed its maiden flight in 1983. It started the indigenous development of a commuter plane in 1989 that first flew six years later. However, Indonesian-made planes never sold successfully in foreign markets. It became clear during the South East Asian financial crisis of 1997 that the government lacked the funds to continue supporting an industry employing around 16,000 workers. Since 1998, Indonesian aerospace manufacturing has been struggling to survive. The case reveals how a sectoral innovation system that never fully developed, failed to transit to a new, sustainable growth path after being confronted with a crisis.

4.6.2 The emergence of the Indonesian aerospace industry and innovation system[181]

4.6.2.1 The origins of Indonesian aircraft manufacturing

Aviators and aircraft designers were already active in Indonesia well before the establishment of IPTN. Their activities were limited to the design and testing of gliders and small plane prototypes, far from what could be referred to as an industrial scale of

[181] The history section relies primarily on five studies: Hill and Pang (1988), McKendrick (1992), Goldstein (2002b), Eriksson (2003) and Amir (2007).

DOI: 10.14267/phd.2016013

production. Their main contribution to the conception of the industry was spreading the idea that aviation can bridge distances in Indonesia.

One of the key designers of this period was Nurtanio Pringgoadisurjo. Nurtanio was involved in the construction of a number of simple gliders (following the famous German *Zögling* design) and a few single-seat aircraft at the Aircraft Research, Experiment and Construction Depot for the Air Force in Bandung. In 1954, he designed the *Si Kumbang* (beetle) all-metal plane of which 3 prototypes were built. In 1958 he produced the basic trainer *Belalang* (locust) prototype, of which 5 units were produced later. In the same year the prototype of the *Kunang* (firefly) sport plane made its first flight. In 1960, Nurtanio and three colleagues were sent to Manila, the Philippines to study at the FEATI Institute of Technology in the field of aeronautics.[182]

In the meantime, not only the Air Force, but also president Sukarno became interested in the achievements of Nurtanio. The Preparatory Agency for Aviation Industry (LAPIP) was set up in 1960 under the supervision of the Air Force. A year later it signed an agreement with Poland about a loan of 2.5 million USD to construct a manufacturing facility near Bandung airport, for training personnel and to license produce a slightly modified PZL-104 *Wilga* plane developed by the Polish *Cekop*. The 44 Indonesian-made versions, known as the *Gelatik* (rice bird), served for agricultural, light transport and aero-clubs purposes. Yet the small plane production has never become a commercial success.

There were several organizational attempts to establish the foundations of an aerospace industry industry. The National Council for Aeronautics and Space (DEPANRI) was created in 1962 and mandated with national aerospace coordination and policy formulation. In 1963 the National Aeronautics and Space Institute LAPAN was founded, a research institute designated to develop aerospace technology and advise on national aerospace policy. After Nurtanio died in 1966, while testing one of his planes, LAPIP was renamed in his honor to Nurtanio Aviation Industrial Institution (LIPNUR). The Berdikari Aircraft Industry, founded a year earlier, was merged into LIPNUR, which was assigned with the task to produce a basic military trainer aircraft and build workshops for after-sales-services, and maintenance, repair and overhaul. To cater to the human resources needs of a newly emerging industry, the government launched an overseas student scholarship programme as early as 1958, financing

[182] There is a bit of confusion in the literature, Amir dates this event 10 years earlier.

DOI: 10.14267/phd.2016013

aeronautical engineering studies in Europe and the United States.[183] Aeronautics education within the country was rather limited. A sub-study programme on aviation engineering was formed in 1962 at the Bandung Institute of Technology. Since there was no clear government strategy and LAPIP was a military unit, only a handful of students graduated from there during the 1960s. Thus in comparison with Brazil, where local engineer training was highly advanced even before Embraer was established, human capital formation in Indonesia was significantly weaker.

A key promoter of industrial-scale aircraft manufacturing in Indonesia was B.J. Habibie. After receiving a doctorate in aeronautical engineering at the Technische Hochschule Aachen in 1965, he remained in Germany and worked for over 10 years in Hamburg for Messerschmitt-Bölkow-Blohm (MBB) where he became vice president and director for technology application. He returned to Indonesia in 1974, accepting the call of President Suharto to become his technology adviser. Habibie's long-term family ties to the president were a key source of trust, and he soon took on high level positions in the New Order government. In 1978, he became State Minister for Research and Technology, and was given the oversight of a number of high-technology projects as chair of the Agency for Strategic Industry (BPIS).

Habibie's industrial development strategy involved four steps. Phase 1 involved technology acquisition by *transferring* already existing technology through licenses. In Phase 2, previously acquired technology would be *integrated* into the design and production of new products. In Phase 3, the existing technology would be further *developed* and investment would be made into new technologies to design and produce new products. Finally, in Phase 4, large-scale basic research capabilities were to be acquired and implemented to generate new, competitive generic technologies (Steenhuis *et al.* 2007).

Despite the lack of a pre-existing technological base and an underdeveloped capital goods sector, the Indonesian government did not hesitate to formulate ambitious high-tech mega-projects, including telecommunications, shipbuilding, the national car project, nuclear energy and aircraft manufacturing. The late 1960s and 1970s marked a period of rapidly increasing oil revenues as a result of the exponential growth of oil

[183] The appearance of aviation on the political agenda may be linked to a 1956 speech by Sukarno on the occasion of the fifth year of independence, in which he highlighted the strategic nature of aviation for the Indonesian military, economy and politics.

DOI: 10.14267/phd.2016013

production.[184] The New Order government expressed its intention to invest the oil revenues into enhancing domestic technological capabilities.

4.6.2.2 From licensed production to co-development

IPTN was founded in 1976 by a presidential degree as a state-owned enterprise with the merger of the assets of the Pertamina oil and gas company[185] and LIPNUR. Habibie, who was appointed as the director of the company, had initially chosen a location near Jakarta. He later accepted the Air Force's offer to use the Bandung facilities of LIPNUR (180 km from the capital) in return for including 'Nurtanio' in the name of the new company. Nurtanio Aircraft Industry (IPTN) commenced operations in two small hangars of 11,000 m^2 on a 45,000 m^2 site outside Bandung on 23 August 1976 and in the same year counted 860 employees. Within two decades, IPTN's facilities had expanded to 437,000 m^2 and the number of employees had risen to 16,000. (see Table 4.13)

IPTN and two other institutes, PUSPIPTEK and BPPT formed the basis of the integrated aerospace program in Indonesia. The Center for Science and Technology Development (PUSPIPTEK) was established in Serpong, close to Jakarta, providing research and testing laboratories. The Agency for Assessment and Application of Technology (BPPT) took over policy coordination of national technology development in aerospace and other high-tech industries. At the same time the domestic supply of aerospace engineering graduates was only slowly catching up with demand. Enrolment at ITB only numbered some 30 plus students in 1980.

Table 4.13 Key financial data of IPTN, 1976-89, compared with the first years of Embraer

IPTN												
Years	**1976**	**1978**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
Employees	860	1,695	3,162	4,742	7,853	10,774	11,713	12,596	13,000	13,300	14,100	14,20
Sales	15.6	34.0	43.5	102.7	106.0	67.5	46.9	86.9	73.4	124.3	149.1	223.7
Profit (after tax)	1.5	6.9	0.9	2.0	7.4	9.5	13.3	0.3	-16.2	1.8	0.4	5.0
Investment	49.2	11.4	41.3	84.1	141.8	139.7	119.4	79.8	205.9	85.8	42.7	54.5
Inv/Sales (%)	315.5	33.5	95.1	81.9	133.7	206.9	254.3	91.9	280.6	69.1	28.6	24.4
Sales/Emp (1 USD)	18.1	20.1	13.8	21.7	13.5	6.3	4.0	6.9	5.6	9.3	10.6	15.8
Embraer (EMB)												
	1969	**1971**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**
Employees	589	n/a	3,323	3,353	4,225	4,104	4,300	4,987	5,957	5,414	6,732	6,877
Sales		21.4	120.4	199.9	228.3	295.7	256.0	269.3	375.5	346.1	439.5	348.2

[184] Indonesian oil production increased threefold from 486 thousand barrels a day in 1965 to 1.5 million in 1976 (BP, 2009).

[185] Pertamina was established in 1957 to extract and refine Indonesia's oil and gas reserves in 1957. Its revenues allowed it to have assets in many other fields including telecommunication, real estate or airline business but it also became a source of funding for Indonesia's ruling elite without accountability, leading to debts amounting to 10 billion USD by 1975 in a time of rapidly expanding oil production. For more on the Pertamina debacle, see McCawley (1978).

DOI: 10.14267/phd.2016013

Comparison of employment and sales: IPTN / Embraer (%)												
Employees	146.0	n/a	95.2	141.4	185.9	262.5	272.4	252.6	218.2	245.7	209.4	206.5
Sales		158.7	36.1	51.4	46.4	22.8	18.3	32.3	19.5	35.9	33.9	64.2

Source: Hill and Pang, 1988, Table 4, p.159; McKendrick, 1992, Table 4, p.60.; Ramamurti (1987)
Note: Values in thousand USD, constant 2000 prices (official exchange rates from World Development Indicators: 8421.8 IDR/USD applied.)

Habibie was very successful in securing deals for technology sourcing. In line with his technology strategy of "start from the end and end at the beginning", IPTN embarked on license manufacturing. Already in 1975[186] a contract was signed with Habibie's former employer, the West German MBB about the assembly of the BO-105 helicopters in Indonesia under license. It is estimated that over a hundred of these models (NBO-105 under Indonesian designation) were built over a quarter of a century, making it the most successful product of IPTN. In 1982 a subsequent deal was signed with MBB to assemble the BK-117, a more advanced helicopter, but it is estimated that only 3 of these were produced in Indonesia. In 1977, IPTN acquired a license from the French Aerospatiale to produce the *Puma* SA-330 (NSA-330) and later the *Super Puma* AS-332 helicopters (NAS-332 under local designation) in Indonesia, from kits shipped from France. Some 20 of these helicopters were produced according to the best estimates[187]. The third rotary wing producer IPTN signed a contract with was Bell Textron (US) in 1984. Production of NBell-412 helicopters started in 1986, with two units produced in the first four years. (See Table 4.14 for an overview of the aircraft and helicopters produced in Indonesia)

Table 4.14 Number of aircraft and helicopters delivered by IPTN (1975-98)

		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Aircraft (Total)		**2**	**3**	**1**	**6**	**3**	**6**	**20**	**7**	**9**	**8**	**10**	**3**	**3**	**4**	**9**	**6**	**2**	**10**	**6**	**7**	**2**	**0**	**0**	**0**
NC-212	Total	2	3	1	6	3	6	20	7	8	8	10	2	2	1	4	3	0	1	2	3	1	0	0	0
	Domestic	*2*	*3*	*1*	*4*	*3*	*6*	*18*	*7*	*7*	*8*	*10*	*2*	*2*	*1*	*4*	*3*	*0*	*1*	*2*	*3*	*1*			
	Export				*2*			*2*		*1*															
CN-235	Total												1	1	3	5	3	2	9	4	4	1			
	Domestic												*1*	*1*	*3*	*5*	*3*	*2*	*9*	*1*	*0*	*0*			
	Export																			*3*	*4*	*1*			
N-250[a]	Total																					1	1		
Helicopters (Total)		**6**	**7**	**5**	**6**	**5**	**6**	**10**	**14**	**20**	**21**	**7**	**10**	**4**	**6**	**2**	**3**	**2**	**1**						
NBO-105		6	7	5	6	5	6	8	8	18	14	7	8	1	2	0	1	2	1						
NSA-330								2	6	2	1														
NAS-332											6			1	2	0									
NBell-412													2	2	2	2	2								

[186] Since IPTN was not existing at that time, the Indonesian partner organization in this deal (and in a later with the Spanish CASA) was Advanced Technology & Teknologi Penerbangan Pertamina (ATTP).
[187] McKendrick (1992, Fig.1, p.50) reports 11 NSA-330s and 6 NAS-332 assembled by 1990. SIPRI estimates 9 NAS-330s assembled between 1981 and 84 and 4 plus 7 NSA-332s over the periods 1984-87 and 2001-07 (SIPRI, 2009).

DOI: 10.14267/phd.2016013

Source: Aircraft delivery figures from *Airlinerlist.com* (retrieved 2010 Jul); Helicopter production figures from McKendrick, 1992, Fig.1,p.50 (IPTN).
Note: a) only prototypes were built of the N-250, it was not produced in series.

Habibie's primary interest was in producing fixed-winged aircraft. The key technology contract that came to shape the trajectory of Indonesian aircraft production and development was signed with the Spanish Construcciones Aeronauticas SA (CASA), the company that Goldstein (2002b, p.528) referred to as "the smallest of the independent European aerospace firms". The 1975 deal permitted Indonesia to produce the C-212 *Aviocar* 19-seater turboprop under license. This design was relatively new (flown first in 1971) and belonged to the expanding niche of commuter aircraft with low airport infrastructure requirements (very similar to Embraer's *Bandeirante*) and offering a versatile utilization for both commercial and military purposes. CASA sent a staff of 30-40 technicians to Bandung to facilitate learning to produce the plane, but it was the C-212's "simplicity in design and construction" (McKendrick 1992, p.43) that contributed to the relative success of the project. The newborn Indonesian aircraft industry had produced five of these aircraft by the end of 1976 and production of the type peaked at 17 in 1981. Most of the Indonesian-made NC-212 airplanes served domestic demand[188]. IPTN had a license to produce 108 NC-212s and had completed 95 by the year 2000.[189] Due to a variety of reasons, 16 of these planes were involved in accidents. (See Figure 4.27 for an overview of Indonesian aircraft production.)

IPTN's cooperation with CASA advanced to another level when in 1979 the two companies agreed to form a joint venture to design and manufacture a 38 to 44-seater twin-prop commuter, the CN-235 (CN stands for CASA/Nurtanio). Entry into the emerging aviation market of Indonesia and the readiness of the Indonesian counterpart to invest in research and development triggered the interest of CASA. For for IPTN the deal meant advancing to the second stage of Habibie's technology transfer ladder ('technology integration', or the development of new-product using already proven technology). This was considered as an in-between stage on the route towards indigenous design capabilities.

In 1979, Airtech was established in Madrid with 70 million USD to coordinate the project. CASA and IPTN became equal partners. McKendrick called the division of labour on the CN-235 "quite unusual", because work was divided in a way that IPTN

[188] McKendrick (1992) reports only 6 planes exported by 1986, 5 for agricultural use in Thailand and 1 for Air Guam; SIPRI lists only the 4 exported to Thailand .
[189] "Toughing it out", *Flight International*, 25-31 July 2000

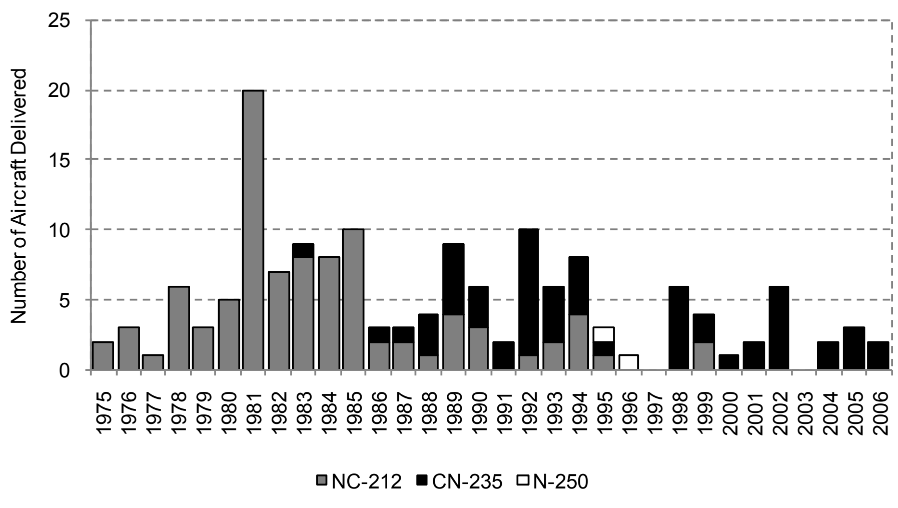
DOI: 10.14267/phd.2016013

designed and produced the outer wing sections, the rear fuselage, the tail and the interior while CASA was responsible for the (technologically more demanding) inner wing sections, forward fuselage, centre wing and engine nacelles (1992, p.45). These parts were then exchanged and final assembly took place both in Spain and in Indonesia.

The design phase (1979-82) allowed for an active knowledge exchange. CASA sent some 60 employees to IPTN to assist design and further support on aerodynamics engineering was received from Boeing. The project was important for IPTN in terms of acquiring and upgrading machinery and tools as well: it started using touch numerical controlled (TNC) machinery in 1981 and by 1985 24 computer numerical controlled (CNC) machines allowed high precision work. CASA also received assistance on wing design from MBB.

The share of foreign components was high: engines, communications and control systems, landing gear and base metal had been produced in the USA and Europe. For IPTN, this was reduced over the years to 20 percent, although the reduction only affected the airframe.

Figure 4.27 Aircraft production cycles in Indonesia (1975-2006)



Source: IPTN, Airlinerlist.com (retrieved: 10 Jul 2010)

Notes: Year of delivery is a close proxy to year of production, for which there is a lack of information. Since many of the planes produced were not sold immediately, there are potential discrepancies, e.g. in 1981, at least 3 of the NC-212s delivered may have been produced in the previous year. In the case of 6 CN-235s produced during the crisis years of 1997-98 for Malaysia, but only delivered later are listed for 1998 based on information from *Flight International*[190]. There are reports of NC-212 production in Indonesia after 2000, but exact number and year are unknown.

[190] "Indonesia tries to rescue Malaysian IPTN deal" *Flight International* 24-30 Jun 1998

DOI: 10.14267/phd.2016013

Two prototypes were produced by CASA and two by IPTN. One of the Spanish planes, *Infanta Elena* took off in Madrid for the first time in November 1983, followed by the Indonesian *Tetuko* a month later. The division of labour between the parties became a source of major problems for the airworthiness certification. When the CN-235 received certification of the American FAA in December 1986, it was only valid for the prototypes assembled by CASA, not by IPTN (Amir 2007, p.287). Lacking bilateral agreement between Indonesia and the USA (the USA was demanding an independent aviation authority in Indonesia), IPTN had to turn to other agencies, and finally received certification from the British Aviation Authority in 1995. This was crucial for access foreign markets. However, customers remained cautious and preferred the planes assembled in Spain to those made in a developing country. However, Eriksson (2003) notes that by this time CASA had already sold their planes to potential buyers. Exports of the Indonesian-made CN-235 planes covered Southeast Asia (Brunei, Malaysia and South Korea, with a total of 17 planes) as well as Pakistan (3) and the United Arab Emirates (7)[191]. On the global market the (Indonesian and Spanish made) CN-235s achieved only moderate success, with a around 5% share in the 20-45 seat segment by 1990[192]. By 2007 a total of approximately 234 CN-235s have been produced by CASA and IPTN together.[193] Analysts considered the realization of the CN-235 venture as a success[194] for the newly emerging industry of Indonesia and it brought significant prestige for Habibie.

Table 4.15 Key performance characteristics of IPTN's and competing aircraft

Manufacturer / Aircraft Type	First Flight (Year)	Max number of seats	Max take-off weight (tons)	Max cruise speed (knots)	Fuel consumptiona (kg/h)	Max Cruise Altitude (feet)	Max Range (km)
Embraer EMB-120 *Brasilia*	1983	30	11.5	300	340	25,000	3,600
Saab SF-340	1983	37	12.9	282	350	25,000	3,500
de Havilland Dash 8-100	1983	39	15.6	269	393	25,000	2,800
CASA-IPTN CN-235	**1983**	**45**	**15.1**	**248**	**348**	**18,000**	**4,900**
Aerospatiale/Aeritalia ATR-42	1984	50	16.7	265	385	25,000	4,600
de Havilland Dash 8-300	1987	56	18.6	287	457	25,000	2,400
Canadair CRJ-100	1991	56	21.5	460	928	37,000	3,400
Embraer ERJ-145	1995	50	22.0	447	n/a	37,000	3,200
IPTN N-250	**1995**	**56**	**22.0**	**300**	**n/a**	**20,000**	**2,000**

Source: Regional Airliner Directory, *Flight International* 10-16 June 1992; producers

191 Figures are based on SIPRI estimates.
192 Goldstein (Goldstein 2002b, p.529, referring to Dagnino)
193 "Status Of Programs" *Aviation Week & Space Technology*, 10 November 2008.
194 In 1991, CASA even sold the license to produce 50 CN-235s by Turkish Aerospace Industries in a 550 million USD deal. As for the safety record of the plane, out of the 43 assembled in Indonesia, 3 aircraft were lost in accidents; and another 6 of the Spanish-made planes were involved in crashes.

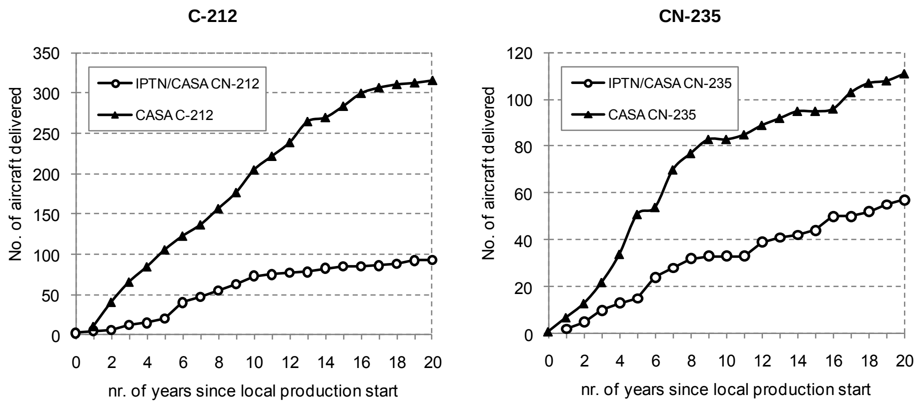
DOI: 10.14267/phd.2016013

Note: a) at long-range performance

In comparison with similar aircraft, the technological level of the CN-235 in many ways met industry standards. In the early 1980s, almost exactly at the same time as the CN-235, five major aircraft projects were launched in the 30-50 seat range around the world. The competitors of CASA and IPTN were Embraer's EMB-120 *Brasilia*, the Swedish Saab SF-340, the Dash-8 by de Havilland from Canada, and a French-Italian venture's ATR-42. The CN-235 compared rather favorably in terms of fuel consumption and range, but this came at a cost of speed and cruising altitude (see Table 4.15).

Figure 4.28 shows the cumulative output of the same aircraft during the first 20 years of production in Indonesia and in Spain, transposed to a common starting point (year 1 refers to the year of the first delivery). The steeper growth of Spanish output in the initial years indicates the difference in manufacturing capabilities and the flatter learning curve of the Indonesian industry. The fact that Indonesian production flattens out sooner (at around 90 deliveries in the case of the C-212 and around 60 in the case of the CN-235) while CASA's deliverys continued to growing reveals Indonesia's sales problems.

Figure 4.28 Comparison of cumulative aircraft production in Spain and Indonesia



Source: http://www.airlinerlist.com (Retrieved: 16 Dec 2009)
Source: http://www.airlinerlist.com (Retrieved: 16 Dec 2009)
Note: Spanish production does not contain the 50 aircraft assembled in Turkey under license

External knowledge flows were also promoted at the government level. A 1979 technology transfer agreement resulted in collaboration in higher education with the Delft Technical University and the Dutch Aerospace Research Institute NLR and was subsequently renewed as ISARD in 1985 and as APERT in 1990. These last two

DOI: 10.14267/phd.2016013

agreements were supported by Fokker until the company went bankrupt. The collaboration with TU Delft was crucial, since ITB did not offer programs beyond the master's level in the 1990s.

IPTN signed a number of other contracts that were important for the company to gain access to technology, mostly relatively small scale subcontracts and offset agreements with leading western manufacturers. An important agreement was signed with Boeing in 1982 on management assistance. Over the years, around fifty advisers came to IPTN and trained IPTN staff in Seattle, including the son of Habibie, who later became the director of the company. In a small offset contract in return for the flag carrier Garuda acquiring Boeing aircraft, IPTN was selected to produce the trailing edge flaps of the B-737s (to a value of 30m USD) and to assemble stowage bin frames for B-767s (for 1m USD). In a 1986 agreement, Grumman of the US agreed to train IPTN engineers at its home plant. In 1986, Indonesia signed a deal to purchase 12 F-16 fighters from General Dynamics and to produce parts and components to offset the 337m USD deal The components included forward engine access doors, wing flaperons, fuel pylons, main landing gear doors, graphite epoxy skin, and vertical fins in a value of 52m USD[195]. A 1990 deal with the Dutch Fokker included a 35 per cent offset arrangement for any F-100s bought by Garuda, including the production of wing, tail and other primary components. However, the expected full order was never realized. A 1980 deal with General Electric resulted in the establishment of a Universal Maintenance Center in Indonesia six years later, to perform maintenance, repair and overhaul (MRO) of aircraft and industrial engines in the region made by GE. This deal is significant for making Indonesia a competitor of Singapore which focused on becoming a regional MRO hub for the aviation industry.

4.6.3 Going it alone till the abrupt end

Once the CN-235 development project had been realized, Habibie believed that IPTN was ready to develop an aircraft independently. His intention was to launch a commercial aircraft for dual military and civilian use[196]. The initial plan of the engineering team was to design a 30-seater replacement for the aging Fokker F-27s flown by Indonesian airlines, but a subsequent market research found that demand is

[195] Sources contradict on the value of the offset deal; McKendrick reports 17.7m (1992, p.44), SIPRI reports 52m USD (SIPRI 2009).

[196] Amir's interview with Habibie (2007, p.287)

DOI: 10.14267/phd.2016013

greater for a 50-seat commuter. Habibie announced the launch of the N-250 project at the 1989 Paris air show.

IPTN signed an important technological agreement in October 1994 with Lucas Aerospace Flight Control System to develop an advanced flight control systems for the N-250 using the fly-by-wire system developed by Lucas and Liebherr Aero Technik. The 3-axes system was an innovation for propeller-driven planes. To further emphasize that commercialization was the cornerstone of the N-250, IPTN opened a branch office in Seattle and in 1995 made a number of agreements with the local government of Mobile, Alabama and US investors to produce the N-250 in the USA at the to-be-established 'American Regional Aircraft Industry'. In addition, British Aerospace showed interest in manufacturing the N-250 under license in the UK. Habibie claimed that orders amounted to 189 planes by the 3 Indonesian airlines and a European leasing company.

The project budget was initially planned to be 600 million USD, however it increased to 1.2 billion USD along the road. The work started with a team of 30 engineers and the team grew to over 1,500 production personnel. To fill the budget gaps President Suharto decided to allow IPTN to use an interest-free loan of 185m USD from the reforestation fund[197] (and offered the Forestry Department a 5% royalty from all future sales in return). With this cash injection IPTN succeeded in rolling out *Gatotkaca*, the first prototype of the N-250 on Patriots Day in November 1994. The plane completed its maiden flight in August 1995. So far, only two prototypes have been built. Work on a third one came to a halt in 1998. The first two airplaces clocked around 850 flight hours, half of what would have been required for certification. The plane never received an airworthiness certificate[198] and the financial crisis of 1997-98 brought the project to an abrupt end.

The unsuccessful commercial launch of the N-250, an apparently technologically innovative plane, points in the direction of systemic failures in the Indonesian aerospace innovation system. First of all, the idea of 'going it alone' was in sharp contrast with the strategy of other foreign producers as well as airlines' expectations, at a time when the

[197] The fund was established to finance preservation and rehabilitation of Indonesian forests in which all forest concessionaires had to contribute. A subsequent lawsuit against President Suharto by a group of NGOs was dismissed and IPTN never eventually paid back the loans as the loan was converted into government shares. Devastating forest fires in the following years were grim testimonies of the misconduct.

[198] Major causes for delay were partly of organizational, partly of technological nature (including concerns with the application of the fly-by-wire system).

DOI: 10.14267/phd.2016013

global landscape was being dramatically reshaped by the post-Cold War recession. The list of confirmed orders for N-250 was alarmingly short on foreign buyers. Airlines were increasingly opting for regional jets instead of propeller planes, and to cut operating costs preferred manufacturers that offered a whole range of product lines of one family. As the lower rows of Table 4.15 show, the N-250 fitted more in the product lines of the 1980s than in those of the 1990s. While the propeller-driven commuters' market was shrinking, the novelty it offered (fly-by-wire system) was not enough to convince potential buyers. Cross-border R&D and production ventures were the new sources of innovative solutions in new planes. While the vertical integration of the design and production of almost all of the modules (except for the engines) was functioning in the 1970s and 1980s, it became too expensive a solution in the 1990s. Over the 1990s, the changes to a system of increased global competition and collaboration caused many famous European and North American producers to be taken over or to go bankrupt.

Still, IPTN took the risk of going against the trend, and saddled itself with development expenses that by far exceeded its profits and even its turnover. The reason such an endeavor could go ahead was due to the very nature of the innovation system. It was not a system aiming at greater market success by commercial and technological interactions, but more a rather expensive public experiment to prove Habibie's theory that technological capabilities can be acquired through 'learning-by-doing'. The tougher global competition in the industry was no longer conducive to these kinds of experiments. The influence of one strategist on determining the technological capabilities was excessive, and correcting mechanisms and institutional checks and balances were missing from the system of innovation. These are exemplified by what McKendrick (1992) showed to be as underdeveloped managerial capabilities. The lack of foreign sales of existing aircraft should have alerted the staff to international market signals.

Sufficient foreign demand for a new plane can accelerate certification in the respective country. But since this was not the case and since the domestic certification process revealed the need for further technological adjustments, the Indonesian aircraft industry started to fall behind the global leaders.

DOI: 10.14267/phd.2016013

4.6.3.1 The emerging innovation system: increases in size and performance

There is, nevertheless, historical evidence that an aerospace innovation and production system *was emerging* in Indonesia. This evidence is summarized below. The main elements (input resources) that increased the size of the innovation system are the following:

1. **Actors:** The two main (interrelated) actors providing financial input in the system were the Indonesian Government and the Air Force. IPTN was assigned with the entire range of industrial activities from design to production and marketing. The actors that influenced the course of innovation included foreign technological partners, such as MBB, CASA, Boeing and other manufacturers offering parts and components production for IPTN. A major gap in the system was the lack of domestic private actors and private capital investment.
2. **The institutional set-up:** Government legislation provided a protective environment favorable to an infant industry. This included an import ban on competing airplanes and a guaranteed domestic market (the Air Force and state-owned carriers were forced to buy domestically produced aircraft), as well as an exemption from the “buy Indonesian” policy that compelled other state-owned enterprises to purchase domestic inputs. State ownership of IPTN coupled with Habibie’s influential role in multiple capacities[199] ensured a rather soft budget constraint for the company.
3. **Capital input:** Investment totaled at 6.5 billion dollars by 1989. The exact use of this amount remains unknown (including what was spent on technology acquisition or R&D), but it roughly indicates the cost of technological capability accumulation. Additionally, at least 1 billion dollars were spent on the development of the N-250.
4. **Technology input:** Even before the establishment of IPTN, the Air Force had an R&D depot and a few small planes were designed in Indonesia. Between 1975 and 1986, licenses were acquired for four helicopter types (from MBB, Aerospatiale and Bell) and one aircraft (from CASA). In connection to these projects, at least 50 foreign experts worked at IPTN. A team from Boeing was providing organizational support for the management. As a result of offset deals,

[199] Apart from being CEO of IPTN, Habibie was the chair of the Agency for Strategic Industry (BPIS), the Technology Adviser to the President and held the position of Minister for Technology and Research between 1978 and 1998. Following two months of Vice Presidency, Habibie became the President of Indonesia in May 1998, which lasted until October 1999.

DOI: 10.14267/phd.2016013

IPTN produced components for Boeing, British Aerospace, Fokker, General Dynamics aircraft in the late 1980s and 1990s. A Universal Maintenance Center was also established with the help of General Electric in 1980.

5. **New machinery:** By the end of 1985 IPTN operated 63 computerized numeric control (CNC) and 51 touch-in numeric control (TNC) machines, 156 conventional milling machines, 1 chemical milling machine and 3 autoclaves for plastic bonding. By the late 1990s, nine additional TNC machines and 24 milling machines had been added (Table 4.16).
6. **(Skilled) labor input:** By 1989 the workforce of IPTN grew to 14,200, peaking at at 16,000 in 1997. Many employees were blue-collar workers who received in-house training, but a large share of the engineers was trained in Europe and North America. Partners (including CASA and Grumman) also offered additional in-house training for IPTN staff. University graduates constituted around one-sixth of the employees of IPTN in the 1980s. Many of these had studied abroad with government or company scholarships. Locally, the Bandung Institute of Technology was offering an 'Aerospace Engineering' optional program from 1962 onwards, which was formalized in 1991. A department of aerospace engineering was only created in 1997. A 'Materials Engineering' program has been offered since 1993, although scholarships were given a decade earlier to assist the formation of the program.[200] However, in comparison to other aircraft producing countries, the provision of high skilled labor had major shortcomings, mainly due to the fact that all high-tech industries were developed at the same time virtually from scratch, where a philosophy of learning-by-doing prevailed.

Table 4.16 IPTN's machinery for aircraft manufacturing

	Computerized Numeric Control (CNC) machines	Touch-in Numeric Control (TNC) machines	Conventional milling machines	Chemical milling machines	Autoclaves for plastic bonding
1985	63[a]	51	156	1	3
2000	63	60	180	1	3

Sources: McKendrick (1992) and "Toughing it out" *Flight International*, 25-31 Jul 2000
Note: (a) Number of CNC machines expanded in 1985 from 24 to 63

[200] Information retrieved from BIT's website; "Faculty of Mechanical and Aerospace Engineering, General Information and History" (www.itb.ac.id)

DOI: 10.14267/phd.2016013

The significant innovative efforts made over the first two decades of coordinated industrial development activities had tangible results. Here is an indication on the performance of the aerospace innovation system:

a. **New products:** Direct outputs of the innovation system are the co-developed CN-235 and the N-250 prototypes, both highly complex technologies that were even new to the world. A number of new-to-the-country innovations included the aircraft and helicopters produced under license as well as the parts and components produced for foreign manufacturers.
b. **New production processes:** Although there were some changes in the production processes along a product cycle, McKendrick (1992, Fig.2, p.54) shows no evidence of efficiency gains.
c. **Market share:** IPTN has produced almost 100 of the NC-212 aircraft and more than 140 of the helicopters under license, almost entirely for the Indonesian market. The CN-235 cornered 5% of the global market, mostly due to the sales of the Spanish-made planes.
d. **Sales and value added:** Within ten years of its operations, IPTN's turnover increased to 87 million dollars. In comparison with the Brazilian national champion, average sales of IPTN in the first decade of production, grew more slowly, hardly reaching one third of the sales levels of Embraer.[201] By 1993, IPTN's sales increased to 193 million USD. By 1996 the total Indonesian aerospace industry's value added had increased to 433 million USD. Yet the industry has not become competitive and Indonesian exports were restricted to a few barter deals of 5 NC-212s and 8 CN-235s.

4.6.4 Crisis and interruption without transition

4.6.4.1 Crisis in a still emergent industry

Already during the lengthy final design and certification process of the N-250, in 1995, at Indonesia's 50th anniversary of independence, IPTN announced the development of a new regional jet, the N-2130[202]. Had it been successful, the financing scheme of the

[201] The total sales of IPTN between 1977-86 was around 607 million dollars, for Embraer (1970-79) it was 1893 million dollars, We converted current sales figures to US dollars and deflated to constant 2000 series using WDI data.

[202] N stands for Nusantara, 2 for twin engines and 130 for the number of passengers (The plane would be offered in 3 sizes, with 80, 100 and 130 seats). (See Goldstein 2002b, note 2 p.530 for a more critical interpretation.)

DOI: 10.14267/phd.2016013

project could have been called 'innovative'. In 1996 a separate financing company was created, PT DSTP[203], to raise the estimated costs of 2 billion USD by selling shares to domestic investors, state-owned companies as well as for families (Mursjid 1998). PT DSTP would own the prototypes as well as any intellectual property related to the aircraft. The investors were supposed to receive royalty payments from the time when the N-2130 would enter into production (not before 2003, according to a 1998 schedule). However, the company failed to raise more than around 1/20th of the required capital. No potential foreign partners showed serious interest in investing and analysts also dismissed what Goldstein (2002b, p.530) called a "folly". In the meantime, while IPTN was also looking for an investor to finance the remaining 90m USD required for the certification of the N-250, Suharto signed a letter of intent to the IMF agreeing to stop financing the grand projects, including those in the aircraft industry, in return for a bail-out from the Asian crisis, which hit Indonesia the worst among the East Asian economies (Hill 2000). Even when Habibie became president of Indonesia in May 1998 for over a year , the government could not provide more funds for the industry, which had accumulated 570m USD in debts by 1999 (Goldstein 2002b). In September 1999 DSTP was dissolved and the investment into the N-2130 aircraft was written off as sunk costs.

The crisis not only prompted all the development projects of IPTN to be suspended, but it affected its sales as well. The Malaysian air force was renegotiating a deal on 6 CN-235 aircraft that were not delivered on time in 1997. IPTN had to pull out from bidding for an Australian air force contract due to its inability to offer a competitive financing scheme[204]. In response to the crisis, IPTN was diversifying into non-aviation related products (car and agro industry) and cut its workforce from 16,000 in 1997 to 10,598 in 2000 (by more than 4,000 from 1999 to 2000).[205] IPTN changed its name to PT Dirgantara Indonesia (Indonesian Aerospace, IAe) in the same year. Shifting to the core activities of manufacturing aircraft parts for Boeing, Airbus and British Aerospace, IAe also made further attempts to market the CN-235s and has produced a few. It is struggling to find investors for the N-250 (an attempt of a partnership with China failed). While there are still further attempts to launch a new 19-seater aircraft, the N-219, the most lucrative business for IAe may well be the MRO activities. Today, the

[203] DSTP is short for "PT Dua Satu Tiga Puluh", or "2130 Company". Its mission was to provide finance for high-tech endeavors in the fields of aerospace, maritime transportation and communications.
[204] "IPTN Phoenix falls before Australian competition decision" *Flight International*, 8-14 Jul 1998
[205] "Toughing it out" *Flight International*, 25-31 Jul 2000

DOI: 10.14267/phd.2016013

company employs some 3,700 persons and produces the military version of the CN-235 and also the NC-212 (license extended for the -400 series in 2006) and NAS-332 *Super Puma* under license[206]. Most recently a new agreement was signed with Eurocopter in 2008 to construct the tail booms and fuselage of the latest version of this helicopter, the EC725/EC225, production of the first of the 125 units planned began in January 2010. The deal also included assistance during the early stage of cooperation.[207]

At the same time, it is interesting to see the contrast in the follow-up story of the CN-235 at CASA. The Spanish partner also chose to go it alone with the further development of the aircraft. The resulting stretched military transport version is capable of carrying 50% more payload with new engines. The C-295 made its maiden flight in 1998 and has been selling rather successfully, owing partly to the boost brought about by CASA's merger into the Europe defense corporation EADS. Further modified versions of the CN-235 were instrumental in providing EADS with a foothold on the American defense market by providing maritime patrol planes for the coast guard[208].

4.6.4.2 Interruption in an emergent innovation system

The Indonesian industry ran out of steam during the mid-1990s. Despite all the efforts and achievements, the innovation system was not mature enough to ensure competitive sales in the commuter market. At the same time, the direction of search for new innovative solutions was in mismatch with changes in the global competitive landscape. The Indonesian strategy of self-reliance was diametrically opposed to the alliance-favoring solutions that the global aircraft industry was transiting towards since more than a decade ago. The decision to develop the N-250 almost alone made the project too expensive and technologically less reliable compared to competitors using risk sharing partnerships for co-development and co-production (see Embraer's success with the E-145 regional jets). Even access to blatantly unlimited government resources was insufficient to gain certification and a critical mass of foreign export deals. Consequently, without fundamental institutional changes the industry had little chance of continuing to grow.

In this setting the aircraft industry was unprepared to face the East Asian financial crisis and the loss of its only financial resource, the Government. The attempt to raise "private" capital through the DSTP project and the efforts to find foreign investors

[206] *Flight International* 28 Oct 2008
[207] "PT DI makes components for France's Eurocopter" *The Jakarta Post* 28 Jan 2010
[208] "EADS-CASA all at sea" *Interavia*, Summer 2006

DOI: 10.14267/phd.2016013

indicates that IPTN and the government were aware of the problem. However, these small steps were not enough for the company to weather the crisis in which both innovation and production came to a still stand. The effect of the interruption was more devastating in Indonesia than in any other country developing a latecomer aerospace industry:

1. **Reduction in the capital flows:** In accordance with the agreement with the IMF, all government support to IPTN was cut, leaving the company virtually without sources of finance. Part of the equipment and machinery in research institutes was also dismantled and sold abroad.
2. **Reduction of human capital inflows:** The crises had major consequences on the aeronautics education system. In 2000 the enrollment in aeronautical engineering at ITB was reduced from 70 to 50 students, while the program was given a more general profile. Many of the staff were forced to take a sabbatical year abroad, a number of experts left forMalaysia or the Netherlands.
3. **Halt of innovative activities:** As a result of lack of funding, IPTN shelved the N-2130 project and the certification of the N-250.
4. **Production output:** Apart from the planes already in an advanced stage on the production line, the factory came to a halt.
5. **Sales and value added:** Value added further plummeted from as low as 24 million USD in 1998 to 4 million in 1999. Most indicative of the lack of transition ever since is that value added could not exceed 37 million in 2005.

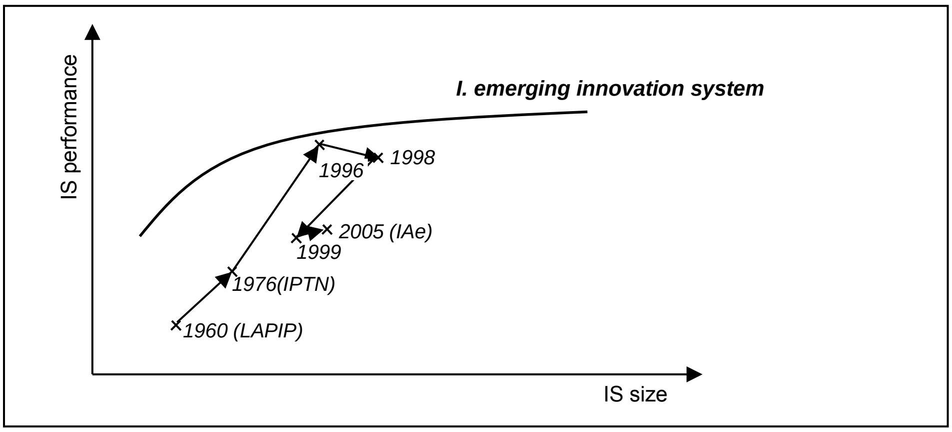
4.6.5 Conclusion

4.6.5.1 Emergence and interruption

Based on the findings in section 4.6.4, Figure 4.29 provides a summary overview of the emergence, growth, stagnation and eventual collapse of the Indonesian aerospace innovation system. In the years preceding the establishment of IPTN in 1976, we can see an increase in both the size and the performance of the system. The increases were due to the establishment of a manufacturing facility and the inflow of Polish technology. This resulted in new-to-the-country products and presumably process innovation along the learning curve.The institutionalization of innovative activities, through the establishment of LAPIP in 1960 did not start from scratch, since Nurtanio had already been active during the late 1950s and had designed a number of new small planes.

DOI: 10.14267/phd.2016013

Figure 4.29 Emergence of the Indonesian aerospace innovation system



(Author’s compilation)

Between 1976 and 1996 the innovation system’s size continued to increase and performance improved to hitherto unprecedented levels. The expansion of the system was driven by the expansion of IPTN. Though the share of investment dedicated to R&D is unknown, we may assume that learning by was associated with increased resources to assist learning, see Table 4.13). New technology was provided through licenses for helicopters and aircraft and international exchanges of staff. The improved performance of the system manifested itself in increased production figures (Table 4.14). The arrow to 1996 hides the winding growth path, but the growth trend only seems to be interrupted with the maiden flight of the N-250. The mounting expenses, the failure to certify the plane and failed attempts to commercialize previous ones indicates a stagnating or slightly declining system that reached its critical turning point with the financial crisis in 1998, followed by a sharp drop in physical and human capital available in the system, which halted all work on new products.

4.6.5.2 Why did Indonesia fail to make the transition to a new growth trajectory?

The development of the Indonesian aircraft industry stalled during the emerging phase. It remained an infant industry and was unable to make the transition to sustained competitiveness. Why did it fail to do so? First of all, creating a viable aerospace industry is never an easy task. Aircraft manufacturing is among the technologically most complex, highly capital-intensive industries. For a country with no experience in high-tech manufacturing to enter this industry, it had to take extreme risks and deal with a great deal of uncertainty. The need to cope with this uncertainty and overcome shortcomings of infrastructure, human capital and physical capital were theoretically sound arguments for government intervention. Indeed, there was a congenial political

DOI: 10.14267/phd.2016013

environment during the whole development of the industry right until the crisis (McKendrick 1992). Many comparable policies were applied by Western and emerging country governments to support their aerospace industries.

The need for long-term strategies and solid institutions is crucial, as the failed case of Argentina indicates. In this respect, there is no doubt that Indonesia was diligently following a clearly formulated strategy (Habibie's four steps) from the mid- 1970s to the late 1990s. But was the strategy feasible in the first place? Habibie implemented a technology push strategy. It gave too much priority to technology development over financial and marketing considerations (Goldstein 2002b). In particular it was not compatible with the global competitive environment. Even if there is evidence that both at the company and at government level Indonesia made serious attempts to sell IPTN's planes and considered market demand, this was not feasible given the lack of advanced engineering experienced in related high-tech activities and the lack of human resources. The problems with the certification process of the N-250, the integration of the fly-by-wire system and the underdeveloped managerial capacities indicate serious shortcomings in IPTN's technological capabilities.

Despite the lack of sales of the Indonesian made CN-235 and despite the already evident reorganization of the global aerospace industry, IPTN tried to sail against the wind, alone. Contrary to Singapore, with hardly any feedback mechanisms from actual or potential consumers or from other actors of the "innovation system", Indonesia managed to completely disregard the competitive environment. A possible strategy to realize a transition to a more sustained competitiveness should have started with the identification of the desired core competences of Indonesian Aerospace. This might not have been the manufacturing of a complete aircraft, but rather the production of parts and components, with which the company could have participated in global supply chains.

Excessive government attention for aerospace in a developing country has had the unintended consequence of shifting much needed resources (including policy focus) away from other promising sectors. A look at Indonesia's industrial development in a broader context justifies these criticisms. According figures presented by Hill (1990), the disproportionately high levels of protection for engineering and metal manufacturing industries received were not justified by the increase in their relative size in Indonesia. We do see aircraft manufacturing an increase in value added increase between 1975 and 986 from almost nothing to 22 million USD, which exceeded the average industrial

DOI: 10.14267/phd.2016013

growth rate of 14.6 per cent per year. However, the share of the capital-goods industries (including transport equipment) actually declined from 14% in 1975 to 13% in 1986 (Hill 1990, Table 2, p.87).

One should also note that it is easy to overestimate the real output performance of Indonesia. Even at the peak of production in 1996, Indonesian value added in aerospace was only 433 million USD. This is only 20 per cent the value of Japan and 30 per cent of Chinese value added. During the 1990s it was trailing Singapore, though producing more than Malaysia and for a few years, even more than South Korea (See Chapter 3).

Aerospace manufacturing may well have been too big a technological jump for Indonesia. The industry was established as an island of high-tech in a sea of low-tech production. Technological capabilities in manufacturing in general were low in Indonesia, not to mention in the capital goods industries. By the time Brazil started to produce commercial aircraft, the states of Sao Paulo or Rio de Janeiro had already accumulated four decades of experience in a broader range of industrial activities. In 1970, one year after Embraer was established, metal products, machinery and transport equipment industries accounted for nearly 29% of Brazilian output (Katz 2000, Table 6 p.1592). Not only was the relative size of the same industries in Indonesia half that of Brazil's, but the technological levels were also much lower. In this respect, the nascent Indonesian aircraft industry was at a disadvantage when it came to attracting experienced engineers, managers or investors from other technologically advanced sectors.

The foregoing analysis shows that the Indonesian aircraft industry has not succeeded in learning to compete. It has accumulated some manufacturing capabilities in a remarkably short period of time, but a sectoral innovation system remained incomplete. It had weak R&D capacities and insufficient source human resources from the domestic higher education system. The sector has also remained commercially weak. Securing foreign sales is paramount to decreasing reliance on government funding and for recovering at least part of the huge sunk costs of the development of the industry. In the end, even the technological capabilities seemed insufficiently attractive for potential investors. The industry never managed to move beyond the emergent phase and was not able to survive the crises with which it was faced. Even without the Asian crisis, innovation was not sustainable in the system. Since 1998, the industry has continued to decay.

DOI: 10.14267/phd.2016013

Chapter 5: Understanding firm-level dynamics: Successive changes in leadership in the regional jet industry

5.1 Introduction

Schumpeterian dynamics constantly change companies' market shares. In their struggle to outperform competitors, innovative companies become industry leaders for a certain period of time, until new challengers "dethrone" them (Schumpeter 1934, 1942; Mowery and Nelson, 1999). Successive leadership changes have characterized the regional jet (RJ) manufacturing industry since its emergence. Many of its features make it a particularly interesting case to help better understand the nature of leadership dynamics. It is a highly turbulent segment of the aerospace industry which has witnessed the entry of firms from advanced and emerging economies and the exit of long-established producers.

Most of the studies on industrial dynamics in aircraft manufacturing have focused on producers of large civil aircraft (LCA) (Moran and Mowery, 1991; Golich, 1992; Frenken and Leydesdorff, 2000; Pavcnik, 2002). The market for RJs, unlike the consolidated LCA market, continues to undergo turmoil. Some of the firms had a long tradition of constructing aircraft (i.e., Fokker, Canadair or British Aerospace and its predecessor Hawker Siddeley), others were relative newcomers (i.e., the Brazilian Embraer or the Chinese Comac). There are different motivations why companies aim at gaining technological competence in this market: some see RJs as the primary aim, for others, it is a stepping stone to enter the more challenging LCA market.

This chapter explores the history of catch up and leadership change that took place in the global RJ industry from the late 1980s to 2010, by studying the co-evolution of technology, the competitive landscape, and strategies of firms and governments. It aims to explain what triggered periods of catch-up and instances of leadership change, and why incumbents lost their leading positions.

Section 5.2 provides a background on the industry, its emergence and the account of two instances of leadership change. Section 5.3 presents the theoretical framework and key arguments to test in case studies. Sections 5.4 and 5.5 offer in-depth analyses of

DOI: 10.14267/phd.2016013

leadership change from the early leaders to Bombardier and subsequently from Bombardier to Embraer, by discussing windows of opportunity, strategic response and the preconditions with respect to all relevant companies. Finally, section 5.6 synthesizes the conclusions from the case studies.

5.2 The regional jet industry and the record of leadership changes

5.2.1 About the industry

RJs are defined as turbofan-engine-powered aircraft carrying typically 30 to 120 passengers at a range of up to 2000-2500 nautical miles.[209] Their size, range and operational costs on shorter distances distinguish RJs from LCA, but both share a lot of technological and operational commonalities. The upper boundary of the regional segment is rather elusive, the smallest members of the Boeing 737 or Airbus 320 families are highly similar to the largest Embraer E-Jets. Propulsion, rather than seating capacity, distinguishes RJs from turboprop-powered commuters. Turboprops may be more economical to operate on short distances than RJs, but are noisier and offer limited cruising altitude, speed and range. Based on the definition applied, many smaller jets of preceding decades would qualify as RJs[210]. However, those aircraft served different markets (connecting main airports rather than extending service to regional airports) and were not optimized for economical operation on shorter routes, which were typically flown by turboprop commuters. RJs show commonalities with larger business jets. They may be identical from a technological perspective, but serve different customers, consequently, demand patterns differ. Nevertheless, the various proximities allow commercial aircraft producers to relatively easily enter the RJ market.

RJ manufacturing does not differ from the structure of the mature commercial aircraft manufacturing industry. By the 1990s, this had transformed into a pyramid-shape hierarchy, with system assemblers on top, followed by primary structures and system suppliers, and component producers on lower tiers. Aerospace companies with multiple competencies can be competitors and collaborators at the same time (Niosi and Zhegu, 2005). Competitiveness in the global aircraft industry is affected by many interrelated factors: by the availability of capital, access to risk-sharing partners,

[209] Given the lack of a single authoritative source for a definition, we derive our definition from Wikipedia, Jane's and various articles of *Flight International*, *Aviation Week & Space Technology* and marketing publications of BAe, Bombardier and Embraer.

[210] For instance, the SE-120 *Caravelle*, the BAC-111 or the DC-9-10

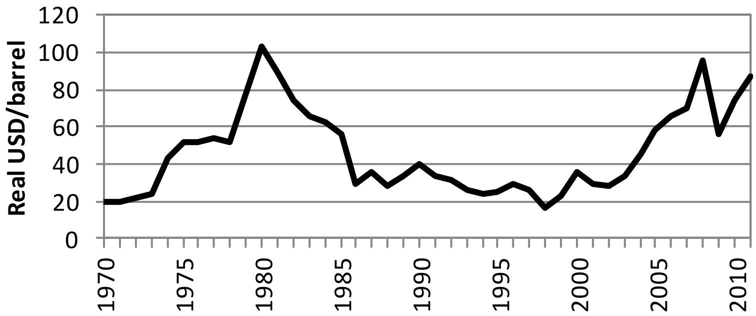
DOI: 10.14267/phd.2016013

government support, by design capabilities and production capacity, by internal organization of corporations and market and by the characteristics of a given aircraft programme, such as price and operation costs, which can benefit from commonality with other models and maintenance arrangements (USITC, 1998). The complexity of factors implies that leadership change is best analysed from a co-evolutionary perspective, considering technology, firms, markets and institutions. Such a framework has been found applicable for the aircraft industry by Frenken (2000).

5.2.2 The take-off of regional jets and the early innovators

The RJ industry emerged at the early 1980s with the introduction of the British Aerospace (BAe) 146 family and the Fokker 100. These became successful due to a combination of factors. The rapidly increasing oil prices of the 1970s increased demand for fuel-efficient aircraft (Figure 5.1). A new generation of turbofan (jet) engines with relatively higher bypass ratio became available on the market, allowing jets to compete with turboprops on shorter routes, which also benefitted from a subsequent decline in kerosene prices in the 1980s. Passengers preferred jets over propeller planes. The liberalization of US air transport services in 1978 opened new markets for smaller jets offering direct connections between regional airports, and connecting regional airports with hubs. Congested hubs discouraged the operation of turboprop commuters carrying fewer passengers but taking up similar or even more airspace as larger jets, given their slower speeds and exposure to wake turbulence. RJs also offered a modern alternative to replace aging turboprop aircraft (Ramsden, 1989). In conjunction, these developments radically changed the airliner market. Airlines could now select smaller jets due to strategic choice, rather than due to technological constraints.

Figure 5.1 Average annual crude oil prices in real terms, 1970-2011



Source: US Department of Transport

DOI: 10.14267/phd.2016013

The industry emerged in Europe rather than in the US, which was by far the leader in aerospace. But McDonnell Douglas (MDD) and Boeing chose to target the apparently more lucrative LCA market, allowing others to exploit the regional niche. The aircraft industry was also advanced in the UK and in the Netherlands, and companies benefitted from strong linkages with their respective governments. BAe and Fokker could exploit their experience of producing and selling various types of aircraft, and established networks of suppliers[211] (Cooke and Ehret, 2009; Broekel and Boschma, 2012).

Many of BAe's and Fokker's strategic choices on design and marketing were emulated by subsequent leaders. Both companies recognized that the key to succeed in the regional market is cost-efficiency, which necessitate an efficient aircraft design and large production capacity. Both companies designed their aircraft in-house. The BAe "146" 109-seater jet was based on an earlier shelved project of a predecessor company, but was equipped with four modern engines (Hewish, 1982). BAe intensified collaborations both in-house and with external partners, including one sharing risk of development and production. Fokker's F-100 twinjet was a fundamentally upgraded derivative of its F-28 model.[212] The F-100 was produced in partnership with British and US-based firms. The 146 design utilized the family concept to maximize commonalities and reduce costs, and was offered in three sizes to meet airline needs, with capacity ranging from 70 to 128 passengers. Fokker also aimed to launch a family, but only managed to introduce a smaller derivative (F-70), due to liquidity problems. Both aircraft differed substantially from those previously available on the market. The BAe-146 family offered a wide cabin,[213] relatively lower noise and the versatility of operations. The F-100 offered relatively lower structure-weight per seat (Table 5.1), due to using composite materials for control surfaces and interior parts (Ramsden, 1989a). The early success of the 146 in the US made BAe the largest RJ producer in the 70-110-seat segment by 1985. BAe-146 production peaked in 1990, but subsequent upgrades

---

[211] Many successful commercial aircraft programs originated from the UK following World War II, i.e. the Vickers/BAC *Viscount*, the de Havilland *Comet* and *Trident* jets, the Vickers/BAC VC10 or the BAC/Aerospatiale *Concorde* (for a more complete list, see "Post-war UK civil aircraft production" *Flight International*, 19 Dec 2006-1 Jan 2007). The Dutch commercial aircraft industry was virtually equal to the activities of Fokker, with its most successful own products, the F-27 *Friendship* and the F-28 *Fellowship*.

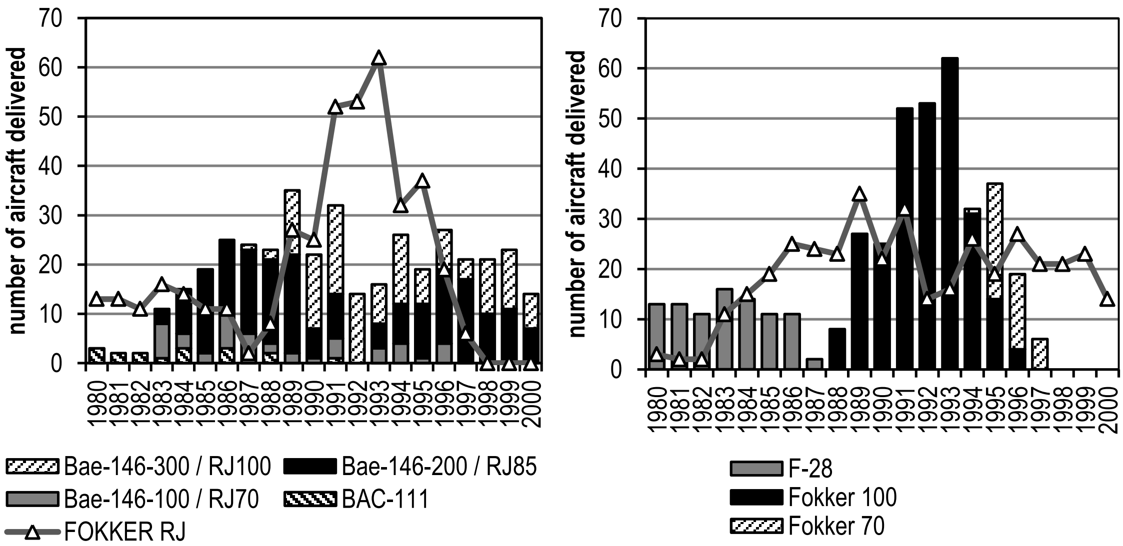
[212] Experts debate the first RJ may have indeed been Fokker's F-28 *Fellowship*, 240 of which were produced from the late 1960s until the mid-1980s.

[213] The costs in increased drag due to the "wide narrow-body" fuselage design were offset by the greater comfort offered by the 11ft-plus cabin width, the size of previous-generation long-haul jets such as the B-707.

DOI: 10.14267/phd.2016013

(the RJ-70/85/100) extended the production run to 2001 (Figure 5.2, left panel). Fokker followed with a delay, as the high costs of simultaneous product launch (a turboprop commuter along the F-100) and exchange-rate volatility led to near insolvency. The Dutch government underwrote its debts in 1987. The strong initial sales of the F-100 made Fokker the market leader in RJs in 1991 (Figure 5.2, right panel). However, Fokker's prices were higher than the new competitors, but too low to recover production costs. Failing to attract investors or secure another government bailout, Fokker announced bankruptcy and ceased to produce RJs in 1996 (Heerkens and Ulijn, 1999, Ligterink, 2001).

Figure 5.2 Number and types of regional jets delivered by British Aerospace (BAe, left panel) and Fokker (right)



Source: www.airlinerlist.com (retrieved: June 2012)

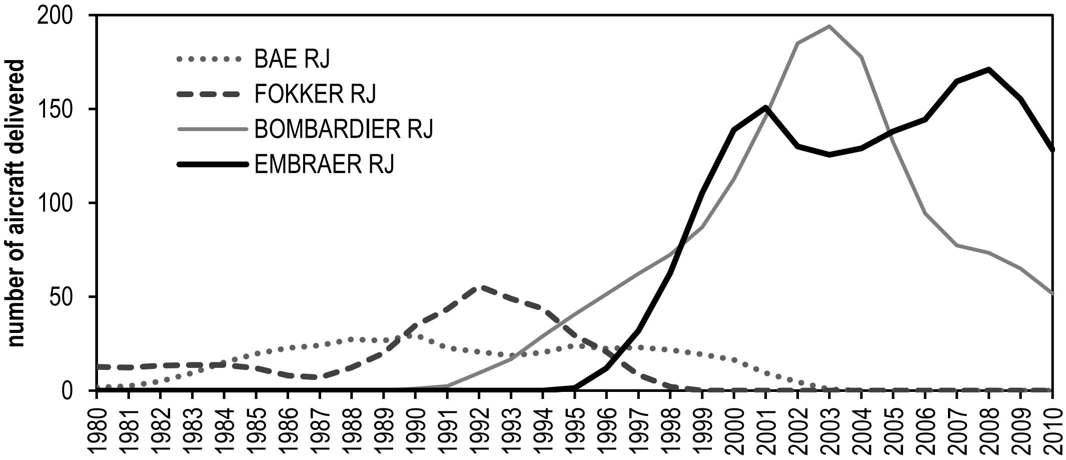
5.2.3 Leadership changes

Changes in leadership in the RJ industry – measured by number of aircrafts delivered – are shown in Figure 5.3. The first leadership change happened in 1995 as Bombardier launched its 50-seat CRJ100/200 *Canadian Regional Jets*. Bombardier, a transport equipment manufacturer entered the aircraft industry through the acquisition of a number of aerospace companies. It successfully transformed a business jet design into the CRJ family, which was subsequently stretched to seat up to a hundred passengers

DOI: 10.14267/phd.2016013

(CRJ700/900/1000). With historically unprecedented delivery rates in the RJ segment, Bombardier produced over 1,700 CRJs.

Figure 5.3 Regional Jet Deliveries, 3-year moving average, 1980-2010



Note: Delivery dates were obtained from the published lists of www.airlinerlist.com (retrieved: June 2012), the accuracy of which could only be verified for Bombardier and Embraer in the respective Annual Reports. Business jets, and other products of the respective manufacturers are not counted. The data includes the following products: British Aerospace RJ: BAC-111, BAe-146-100, -200 and -300 series as well as RJ-70, -85 and -100; Fokker: F-28, F-70 and -100; Bombardier: CRJ100, -200, -700, -900 and 1000; Embraer: ERJ-135, -140, -145, -170, -175, -190 and -195. A 3-year moving average was applied in order to smoothen any discrepancy between production and delivery years.

Initially, Bombardier defended its leadership in the 50-70 seat market against the challenge from Embraer, the emerging Brazilian competitor with experience in turboprop commuter. The 37-50-seater ERJ-145/135 launched following the privatization of Embraer became very successful on the global market, making the company a serious challenger of Bombardier. Embraer gained a stable leadership in new aircraft delivery in 2005 with its radically new design, the larger E-Jet family (ERJ-170/190 models) that addressed the 70-120-seat market. Bombardier’s decision to avoid the above-100-seat market with a purposely-designed jet appears to have cost the Canadian firm its leadership in RJs.

This study aims to shed light on the forces that lead to leadership change, by addressing the following questions: What were the main drivers of sectoral catch-up and leadership change in the RJ market? What affected the timing of instances of leadership change? What did companies gaining leadership do differently from incumbents or other challengers? The following section outlines the theoretical framework and methodology applied in order to find the answers.

DOI: 10.14267/phd.2016013

5.3 Theoretical Framework: A dynamic perspective on sectoral innovation systems

The key elements expected of a theoretical framework to apply for case studies of leadership change are (a) a co-evolutionary perspective on industry dynamics; (b) the need to fit national policies alongside company actions, and (c) accommodate the technology- and capital-intensity of the aircraft industry. For the reasons described below, we argue that an adapted version of the appreciative theorizing framework of Lee and Malerba (2013) is applicable for our study. Industry dynamics is understood as the outcome of the co-evolution of firms, technology, demand and institutions (Nelson, 1994). The strength of a co-evolutionary framework is to help explain the competitiveness of the aerospace industry (Frenken, 2000). Niosi and Zhegu (2008) argued that a broader sectoral innovation systems approach (Malerba, 2002) is more suitable than theories focusing on elements of it, such as product or industry life-cycle theories. Competitive sectors were found to be associated with a well-functioning sectoral innovation system, in advanced as well as emerging economies (Malerba 2004; Mowery and Nelson 1999; Malerba and Mani 2009). It follows that in the context of high-tech industries such as aircraft manufacturing, not only companies, but host governments and local institutions of innovation systems compete for leadership.

We expect to identify discontinuities in the long-term evolution of innovation systems. Periods of incremental change were observed to be punctuated by fundamental transformation in all their building blocks: in firms (Abernathy and Utterback 1978), organizations (Romanelli and Tushman 1994), industries (Tushman and Anderson 1986), and the knowledge base (technological paradigm shifts observed by Schumpeter, 1934; Freeman and Perez 1988, Perez and Soete 1988). In a study of aircraft industries in emerging economies, Vertesy and Szirmai (2010) observed recurrent discontinuities in the evolution of the national and sectoral innovation systems. They found that long-term competitiveness of a sector in a country depended on the ability of key system actors (firms and governments) to adjust to such discontinuities. Lee and Malerba (2013) suggest that discontinuities in the various building blocks of innovation systems present windows of opportunity for latecomer firms to catch-up with and overtake incumbent leaders in a sector. However, the theory implies that in effect, any firm can become a latecomer and new leader. Given the high technological and capital entry barriers to this industry, we contest this and in addition to windows of opportunity and

DOI: 10.14267/phd.2016013

strategic responses, we introduce ‘preconditions’. We discuss below how these three elements can be interpreted for the RJ industry, and what findings we expect with regards to leadership change.

5.3.1 Windows of Opportunity

Lee and Malerba (2013) distinguished three kinds of windows of opportunity for challenger companies, corresponding to the main building blocks of sectoral innovation systems: radical changes in knowledge and technology, in demand conditions and in institutions and government regulation. Our first question is, what types of windows of opportunity contributed to leadership change in the RJ industry.

A radically new technology offers latecomers a window of opportunity to catch-up with incumbents by leapfrogging (Perez and Soete 1988). Incumbents, with capabilities and investments related to an old technology, are often reluctant or inflexible to embrace a newly emerging technology which is clad in uncertainty or which may destroy existing competences (Arthur 1989, Chandy and Tellis, 2000, Christensen 1997, Tushman and Anderson 1986, Henderson and Clark 1990, Chandy and Tellis, 1998). Such “traps” pose potential problems for incumbent aircraft makers who need to recover investments over a long production run. But latecomers may not be in the position to apply a new technology. The commercial aircraft industry has been long described as a “borrower” of technology developed in the military sector and related industries (Mowery and Rosenberg, 1982). A latecomer RJ maker which is not involved in defense R&D or military production, or has not developed the new technology in-house may find it particularly difficult to utilize a new technology for a new aircraft. It may lack certain capabilities to do so, or face political barriers to access. We will return to these cases later when discussing potential strategic response and preconditions for catch-up.

Changes in demand conditions and abrupt changes in business cycles constitute another type of window. Economic growth increases demand for new aircraft, provided that firms have access to growth markets. Yet, as Mathews (2005) showed, while upturns create opportunities for incumbents to expand production in investment-heavy industries, downturns favour latecomers due to the cleansing effect and the liberation of resources. For the aircraft industry sensitive to operating costs as well as purchase prices (Prencipe 2013), downturns can shift demand for more efficient new products. For

DOI: 10.14267/phd.2016013

similar reasons, demand is likely to be affected by changing fuel prices. Presumably, price increases put pressure on airlines to select newer models with lower operating costs, or, probably to a lesser degree, select refurbished older models. Declining fuel prices on the other hand are likely to offer opportunities for incumbents to extend production run of existing models. Changing user preferences, such as passengers' expectation of safety, speed, or comfort, may also influence demand. Preferences might be shaped by supply, but also by chance events, such as crashes.

Regulatory windows of opportunity come in different forms. Prencipe (2013) distinguishes direct effects, or rules concerning the certification of new aircraft, and indirect effects, regulating the exploitation of a country's airspace. Other types of regulatory or institutional windows open with the changing involvement of the government in productive activities, for instance, through nationalization or privatization. Regulatory changes may create restricted windows of opportunity which can apply selectively for certain incumbent and challenger companies, making it difficult to tell *a priori* who would benefit more.

We next examine three cross-cutting features of windows of opportunity: asymmetry, timing and source, given specific characteristics of the aircraft industry. First, the complex structure of the industry (Hobday et al, 2005; Dosi et al, 2003) implies that developers and producers may operate under different political regimes (Esposito and Raffa, 2007), so are influenced by different windows of opportunity. We expect that political actors create asymmetric benefits by regulations. The question is whether windows of opportunity triggering leadership change were applicable to all firms universally or only restrictively. Second, we expect that the timing when windows open matters, considering that the life cycle of aircraft entail long time intervals between development, first delivery and break-even point. A company that reacts too swiftly (or too slowly) to an emerging opportunity – an incumbent or a challenger – is expected to fail if the window closes before it can recover its investments. Third, we expect that not all windows of opportunity are exogenous to the activities of firms or other innovation system actors. Some windows, such as economic crises, world fuel prices or aircraft crashes, arise as random events. But others – potentially regulatory windows – may result from company activity or government legislation, or their strategic collaboration. In this case, we should find evidence for innovation system actors affecting in some ways the nature, timing and length of windows of opportunity.

DOI: 10.14267/phd.2016013

5.3.2 Strategic response

Leadership change requires the active role of firms to recognize opportunities and implement a strategy accordingly (Lee and Malerba 2013). Such strategies involve learning, capability accumulation and innovation (Lee and Lim, 2001; Mu and Lee, 2005). For clarity, we distinguish long- and short-term strategies. Learning and capability accumulation aims to bridge the difference between existing capabilities and those presumed necessary to close the productivity gap vis-à-vis the incumbents (Lall, 1992, Kim, 1980, Bell and Pavitt, 1995). These form part of longer-term catch-up strategies of a late entrant, overarching decades in the context of the aircraft industry, and in the context of emerging economies (Bell and Figueiredo 2012, Vertesy and Szirmai 2010). Over this period several windows of opportunity open, but firms lack the capabilities to respond, or lack necessary preconditions. We will address this issue in the next sub-section. Here we investigate which kind of innovation strategies companies pursued, and what strategic role, if any, did governments play.

When an opportunity emerges, innovating firms decide whether to develop a new product or make improvements to existing ones, which market niches to address, and how to manage the development of a portfolio of new (or improved) products. Innovation strategies rely on past R&D activities, human capital and other capabilities of the firm, or its suppliers. Incumbents and latecomers, in advanced or in emerging economies may all respond to a window of opportunity, but with different strategies. An incumbent presumably prefers a defensive strategy of incremental innovation (Hill and Rothaermel, 2003) in order to recover sunk costs. By increasing variety, they adjust to different user needs as markets mature (Frenken *et al*, 1999) – i.e. by replacing engines or limited re-design by stretching or shortening the aircraft. As new technology mainly originates from component suppliers, this strategy implies incremental capability improvement for a top-tier firm. Radical innovation – launching a new product (family) to exploit a market niche – is a more costly strategy. This involves acquiring new competencies and replacing existing ones. Radical innovation is a more likely strategy for latecomer challengers. Unlearning existing capabilities presents less of a burden, but learning and acquiring new ones may be a costly challenge, but offers the advantages of leapfrogging technology. A supportive government may lower the costs.

There are plenty of theoretical reasons why governments should be considered as strategic actors in aerospace innovation systems. Strategic trade theory suggests that due

DOI: 10.14267/phd.2016013

to the zero-sum competition in this oligopolistic industry, governments and firms act strategically against foreign incumbents and challengers another to maximize rent (Spencer and Brander, 2008). Public policies shape the institutional environment and thus create advantages for firms in various industries (Nelson, 1995). History shows that governments have effectively support local firms, with direct development support, launch aids or public procurement (Eliasson, 2010). Embraer, a late entrant, has been shown to have benefitted from long-term government support apart from its ambitious, entrepreneurial management. For instance, the Brazilian government provided the state-owned Embraer with access to technology, protected its home market, financed product development (and co-development), and helped certification in key export markets (Sarathy, 1985; Moxon, 1987; Ramamurti, 1987; Frischtak, 1992, 1994; Cassiolato et al, 2002). Even after Embraer was privatized, it benefitted from a favourable institutional climate and export credits (Goldstein, 2002a, 2002b; Goldstein and McGuire, 2004; Marques and Oliveira, 2009). However, governments can easily over-reach and push defence-oriented policies without considerations of long-term competitiveness leading to catastrophic failures (Hill and Pang, 1988; McKendrick, 1992; Eriksson, 2003; Hira and Oliveira 2007).

5.3.3 Preconditions for leadership change

In the neoclassical model of perfect competition, any company could respond to an emerging window of opportunity. In an evolutionary framework, path-dependence and technological capabilities limit the set of potential challengers (Nelson and Winter, 1982), as technological advance is cumulative (Nelson, 1994). We aim to test whether preconditions matter for leadership change, and if so, what kind of capabilities successful new leaders possessed which others lacked, and what role governments played in accumulating them.

Preconditions enable companies to effectively respond to emerging windows of opportunity and gain leadership in this capital- and technology-intensive sector. These are a set of technological, organizational and investment capabilities which firms accumulate through a learning process, often spread among actors of an innovation system. A critical mass of technological capabilities and absorptive capacity enable them to recognize the value of new information and implement strategies (Cohen and Levinthal, 1990; Lall, 1992). Management studies have described various capabilities competitive firms need, including innovative or dynamic capabilities (Teece *et al*, 1997;

DOI: 10.14267/phd.2016013

Dutrenit, 2004, 2007), the capacity to invest, establish linkages, manage complex production and innovation networks and meet high quality standards (Hobday et al, 2005; Dosi et al, 2003). Without threshold capabilities, latecomer countries' aerospace industry cannot assume leadership (Baskaran, 2005).

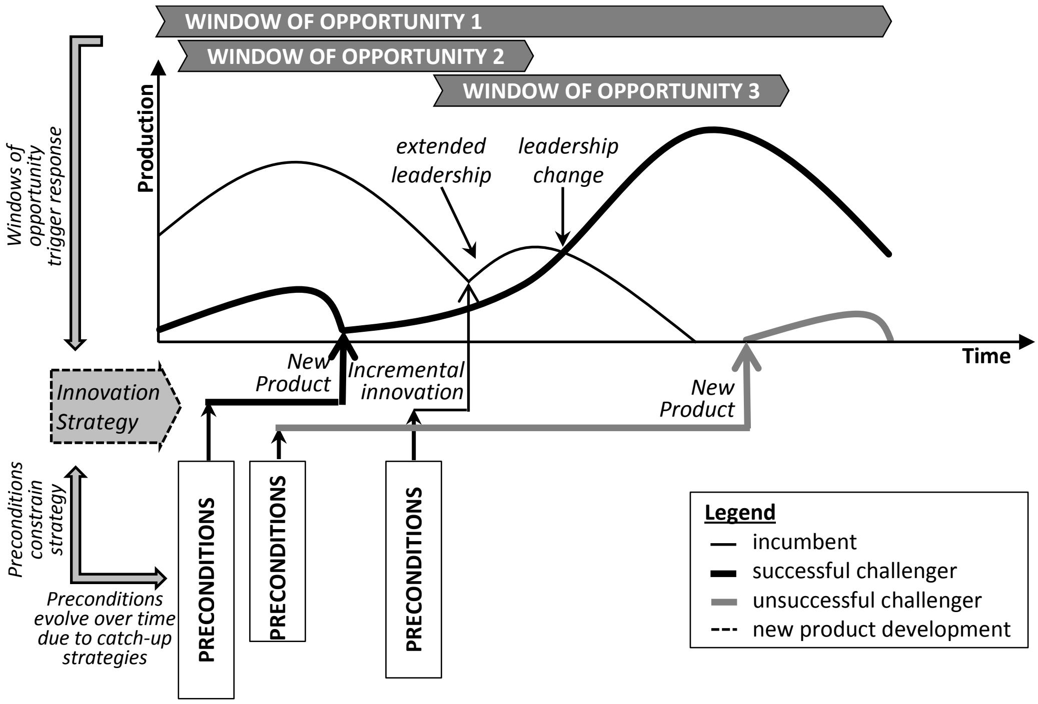
Technological discontinuities can be both competence-enhancing and -destroying (Tushman and Anderson, 1986). In this latter case, firms need fundamentally new skills and competences for market success, thus existing capabilities matter less, which increases the probability for latecomer challengers to rapidly arise. If technological change is competence-enhancing, latecomers need to implement long-term strategies for catch-up and eventually, leadership change (Lee and Lim, 2001).

The empirical literature on aircraft producers that entered the industry since the 1950s (considered as latecomers) suggests that preconditions matter. Successful entry and catch-up was the outcome of learning and capability accumulation, which depended on the provision of skilled personnel and technology from education and research institutes in their proximity and from more advanced countries, as well as access to finance and to foreign markets. Long-term, industry-friendly innovation and trade policies of their respective governments played a crucial role in both advanced and newly emerging economies (Cassiolato et al, 2002; Marques and Oliveira, 2009; Goldstein, 2002b; Vertesy and Szirmai, 2010; Maculan, 2013; Niosi 2013; Lukasiewicz, 1986; Niosi and Zhegu, 2005, 2010; Baskaran, 2001; Mani, 2013; Texier, 2000). At the same time, entry barriers may have been relaxed recently as aerospace firms became ever more specialized, suggesting that preconditions may lose importance. Entry in the 1980s, when RJ producers performed many of their activities in-house,[214] may have had higher barriers than as of the 1990s when the industry became globally interconnected, as shown by the success of specialized suppliers from Japan, Mexico and Singapore (Mowery and Rosenberg, 1985; Kimura, 2006, 2007; McGuire, 2007; Martinez-Romero, 2013; Pang and Hill, 1992; Vertesy, 2013, 2015).

[214] Considering this change in industrial organization, one may distinguish a "less mature" and "more mature" state of the industry. But this is an exaggeration as the aircraft industry retained the dominant design crystallized soon after the onset of the jet age (c.f. Frenken and Leydesdorff, 2000) – typical of what would be considered as maturity in the context of another sector.

DOI: 10.14267/phd.2016013

Figure 5.4 Diagram of theoretical framework



Source: author

5.3.4 *Methodology*

We analyse two case studies of leadership change to understand the salient contributing factors. The main advantage of such a historical-institutional study is that new leaders can be clearly identified retrospectively, along with the relevant windows and the winner strategic responses. For a complete explanation of leadership dynamics,[215] we also discuss the strategies and preconditions of “others”: potential challengers and incumbents that failed.

The case studies will be structured as follows. We first present the windows of opportunity deemed relevant for leadership changes, and then discuss the strategies of new leaders alongside the strategies of other significant companies, including incumbents. Finally, we analyse the preconditions for catch-up and leadership change from the perspective of the new leader and of the less successful others. Figure 5.4 provides a schematic overview linking the elements of the framework to expected leadership dynamics.

[215] This may be a second-best option to a counter-factual analysis.

DOI: 10.14267/phd.2016013

Leadership in the regional aircraft industry can be defined in various ways. Given our sectoral innovation system approach, technology is considered one (certainly important) factor among others that contribute to a firm's market performance. Aircraft manufacturing is a high-tech industry where competitive companies are technologically advanced and innovative. The ultimate success of a technological – or other – innovation is measured by its commercialization (Mowery and Nelson, 1999), so we focus on market performance. Measuring market leadership is challenging. Companies can be compared in terms of turnover or productivity, number and value of new orders or deliveries. It is very difficult, if not impossible, to single out financial data related to RJs specifically, given that RJs are one among many business lines of all the companies examined.[216] It is equally difficult to obtain information on aircraft sales value, as deals typically remain secret and airlines usually receive tailored discounts. Quantity of new aircraft delivery is an accepted measure of market success of a top-tier company. Typically only aircraft with a dedicated buyer are manufactured, and such figures reflect actual demand better than new orders, which are prone to cancellations (Heerkens et al, 2010).

The qualitative historical analyses rely on the rich techno-managerial literature on the aircraft industry. Articles on the business and political landscape, interviews with leading corporate personnel and description of new products are valuable sources for taking stock of capabilities, innovations and strategies. These allow charting the evolution of technology, firms and market conditions, identifying windows of opportunity and understanding innovation and marketing strategies. Newspapers and trade journals, i.e. *Flight International*, *Aviation Today*, or *Financial Times* have often been used as input to studies on the aircraft industry (Frischtak, 1992; Goldstein 2002b, 2006; Cooke and Ehret, 2009). When cross-validated, these sources can be more reliable than survey data. In addition, we use aircraft delivery statistics compiled by Airlinerlist.com (an independent data collection website of aviation enthusiasts) and from Annual Reports of the companies.[217]

[216] Most companies have stakes in the defence or in the corporate jet industry as well. Moreover, as Ligterink (2001) shows, accounting practices easily hide relevant financial information.

[217] In some cases, we found minor differences between the various sources on the quantity of aircraft delivered in a year, typically due to the mismatch between the financial and calendar years, but none that would significantly affect the timing of leadership change and leadership positions.

DOI: 10.14267/phd.2016013

5.4 Bombardier's leadership in the 50-seat segment (1995-2005)

5.4.1 Windows of opportunity

The windows of opportunity that turned out to be instrumental for Bombardier's leadership opened up in different forms over a longer period of time. First of all, continuous technological improvements in jet engines made ever smaller RJs economically viable, offering "technological windows". In comparison with the 3:1 bypass ratio of the Rolls Royce *Tay* engine selected by Fokker for the F-100, the new General Electric's CF-34 engine family introduced in the mid-1980s offered over 5:1 bypass ratio and greater thrust-to-weight ratio (Table 5.1). In addition, the diffusion of information and communication technologies (ICTs) by the 1990s offered efficiency gains both for managing large companies (Esposito and Raffa, 2007), and for optimizing airlines' booking systems.

Second, the "demand window" for smaller jets remained open throughout the 1980s. The 100-seat jets of BAe and Fokker demonstrated the viability of the business model to replace turboprop service with smaller jets. The established hub-and-spoke system in the United States meant that a previously unseen number of communities were now connected to major hubs, served by smaller commuter propellers. Hubs were in competition, and RJ service allowed increasing their reach and hence their market share. The thriving commuter market, however, caused congestion at hubs and a longer travel time in comparison with point-to-point travel. Introducing jets on the feeder routes and for new city-pairs could increase efficiency. Given the opportunity to choose, passengers preferred jet aircraft which they perceived to be safer, more modern and more comfortable than turboprops (Bryant, 1994). In Western Europe, a new stage of economic integration also boosted demand for air travel for relatively shorter distances.

An additional combination of demand and regulatory windows opened in the 1990s, rewarding first movers. The early 1990s also saw a time of declining military spending after the end of the Cold War, global recession, resulting in capital shortage and a long wave of mergers and acquisitions for aircraft producers, and strong price competitions for new aircraft (USITC 1998). Following the Gulf War, oil prices were low and in constant decline (Figure 5.1), allowing airlines to buy more comfortable RJs. Air transport around the world was expanding and RJs could offer more frequent feeder connections. In Europe, the market was opening towards the former Eastern Bloc. In parallel, "scope clauses" introduced in the US turned out to offer a crucial regulatory

DOI: 10.14267/phd.2016013

window. Scope clauses were meant to defend the higher wages of larger legacy airlines' pilots against the lower wages paid by regional airlines, which were established or subcontracted to fly feeder and commuter routes and gained significant market share in domestic air transport. In order to keep a cap on the upward extension of relatively cheaper commuter services, pilot unions and airlines settled with the agreement that subcontractors cannot fly aircraft larger than 50 seats. Scope clauses had a major impact on the regional aircraft industry as they effectively excluded existing RJs with 70-seats from a large part of the regional market. These regulations also gave an advantage to jets rather than modernized turboprops in the 50-seat market, as airlines (given lower fuel price) could offer more frequent connections with RJs (Thomas, 2012). Furthermore, highly publicized commuter turboprop crashes in the US in 1994 and 1995 (ATR-72 and a BAe *Jetstream*) pushed preferences towards jet services.

5.4.2 Strategic response

The expectations on the economic viability of 50-seat jets for routes below 500 nautical miles divided manufacturers in the late 1980s, many betted on turboprops. Most of the European producers with a stake in the commuter market calculated that on a 200-nautical-mile trip (the typical 50-seat route) jets hardly offered a 15 minute block time advantage, while their fuel costs were nearly double. The estimated development costs of a new RJ, about a billion US dollars, seemed unlikely to be ever recovered (Middleton, 1989).

Bombardier became the leader in RJs by essentially creating the 50-seat market, rather than attacking the incumbents in their own size class. Bombardier's strategy to take advantage of the windows of opportunity rested on two elements. First, it accumulated technology and production capacity through acquisition. Bombardier, the transport equipment (snow mobiles, locomotives and light rail transit) producer decided to diversify to aerospace by acquiring troubled companies with advanced products. It acquired (1) the business jet maker Canadair from the Canadian government in 1986, (2) the historical British component supplier (and potential competitor) Shorts in 1989, (3) the business jet producer Learjet in 1990 and, (4) with help from the Province of Ontario in 1992, de Havilland, specialized in turboprop commuters. This established Bombardier as a company offering a range of related products, including business jets, commuters, and components (DePalma, 1998). Second, it simultaneously launched the

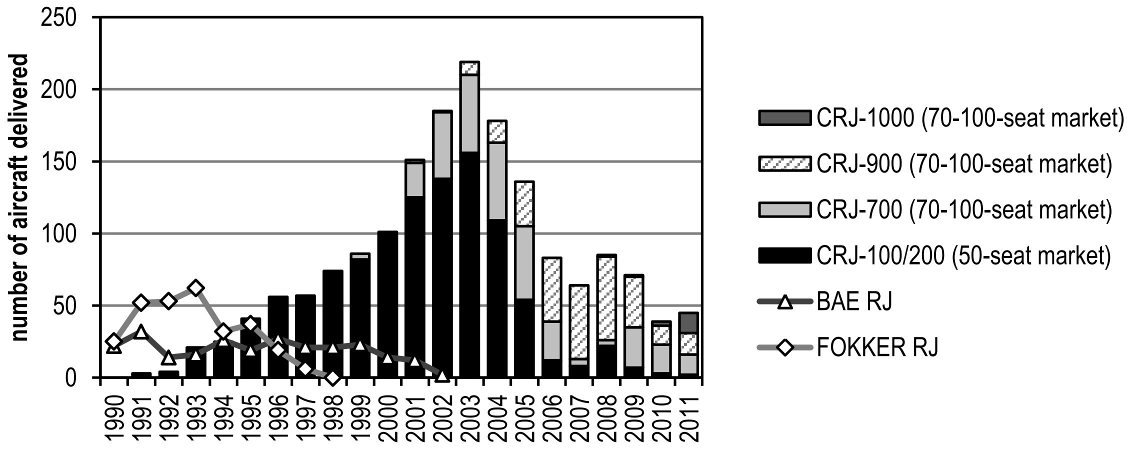
DOI: 10.14267/phd.2016013

Learjet and Global Express business jets, the closely related 50-seat Canadair CRJ regional jet, and the 70-80-seat Dash 8-400 turboprop, all targeting specific niche markets. Bombardier found various ways to reduce costs and offer a competitive price. It financially consolidated the indebted companies and introduced a new management system. It made use of product similarities. The CRJ design relied heavily on the Canadair *Challenger* business jet. By stretching the fuselage and wings, adding additional exits and making smaller modifications to subsystems to meet airline standards, Bombardier kept development costs at about a third the costs of a clean-sheet design. Apart from using the conglomerate's own funds, Bombardier received repayable loans from the Canadian federal and the Quebec provincial governments to finance development.[218] As a result, development time was also reduced: design began end of 1987, the first CRJ flew early 1991, and was delivered by late 1992 to Lufthansa CityLine. Orders from regional subsidiaries of major US and European airlines rapidly increased, and soon Bombardier was increasing production capacity. The demand for the 50-seat jet segment was boosted by the "second set" of windows of opportunity described above (lower fuel prices, application of scope clauses, overall efficiency gains and, turboprop crashes in the US) (Figure 5.5). By 1996, when Embraer's 50-seat ERJ-145 jet entered the market, the competitive landscape had changed significantly. RJ deliveries have overtaken turboprops in the 50-seat market (Figure 5.6), and European producers of RJs were losing the strong price war. The overall costs of European aircraft were significantly higher due to strong currencies and less efficient production; the smallest models (the F-70 and BAe's RJ70) were exceeding the scope clause limitations in the US. As demand for larger RJs increased towards the end of the decade, Bombardier introduced the CRJ700, a 70-seat stretched derivative of the CRJ200.

[218] Of the 275 million CAD project costs, 78 million was government financed, according to Warwick (1991)

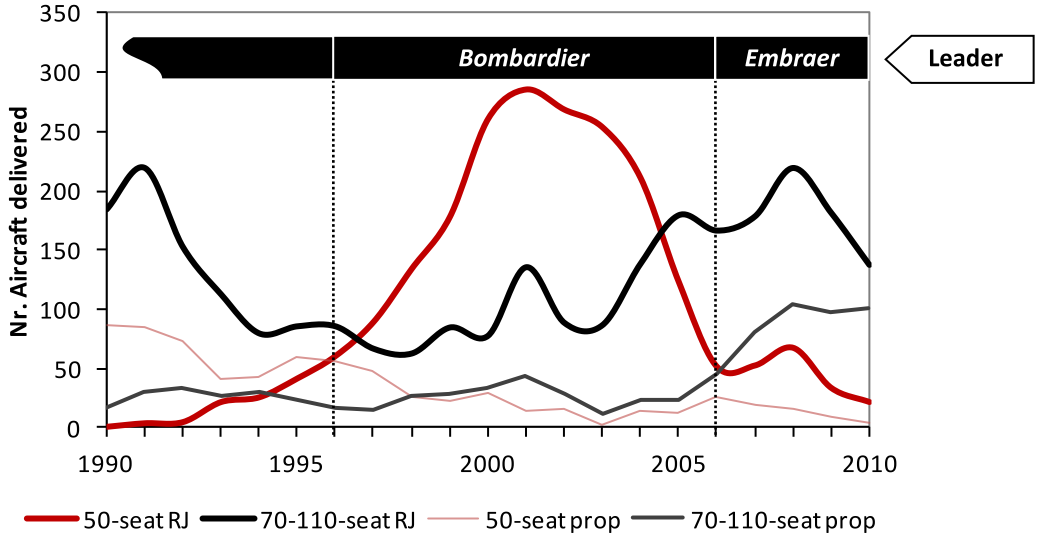
DOI: 10.14267/phd.2016013

Figure 5.5 Number and types of regional jets delivered by Bombardier in contrast with BAe and Fokker



Source: www.airlinerlist.com (retrieved: Jun 2012); Bombardier Annual Reports.
Note: CRJ-100/200-700 served the 50-70-seat segment; CRJ-900-1000 served the 90-100-seat market segment.

Figure 5.6 Size and type competition in the regional market



Source: Own calculations. *Note:* 'RJ' stands for Regional Jets, 'prop' stands for turboprop aircraft. Data covers all ATR, Boeing/MDD, Bombardier, British Aerospace, Embraer, Fokker and Saab models in the 50 (40-60) and 70-110 seat category.

Bombardier could also limit development and production costs by relying on risk-sharing partnerships and focusing on core competencies in system assembly and marketing. An optimal number of partners were selected with the aim to have available capacity to meet large-scale orders, which became a crucial factor – in fact, also

DOI: 10.14267/phd.2016013

contributing to the decline of Fokker.[219] The company realized significant efficiency improvements by introducing "the Bombardier Manufacturing System". This offered cost, time and space optimization thanks to computerizing workflow and logistics (MacDonald, 2012). A good indicator the success of Bombardier's strategy is the fact that it produced more RJs in a year than any of its competitors had before and kept the global market leadership for almost a decade following 1996 (Figure 5.5).

Both incumbents in the 100-seat RJ market chose to sell turboprops for the smaller segment.[220] The companies knew well the tight competition these aircraft were facing. The French-Italian ATR-42 was already launched in 1984. Saab started to develop a 58-seater turboprop (Saab-2000) having recognized rising demand for its 34-seat SF-340 (jointly built with Fairchild). Fokker on the one hand remembered the failure of its VFW-614 44-seat jet in the 1970s,[221] and on the other hand, was already involved in parallel product developments it struggled to finance. Fokker's room for strategic manoeuvring was limited by its size and liquidity position, and the history of the F-100 and F-70 were marked by a number of crises. It only survived a liquidity crisis towards the end of the development phase in 1987 with the help of a government bailout. The higher-than-expected development costs for two parallel programs added to other problems. Solving a shortage of engineers by stopping the F-27 and F-28 production freed capacity but reduced cash flow. The low value of the US dollar and high exchange rate volatility[222] caused Fokker structural financial problems, given its high US dollar exposure: its revenues were in dollars, but costs in Dutch guilders (Ligterink, 2001). Cost-cutting measures did not increase its profitability, but decreased capacity. Access to finance proved difficult at a time of global aerospace mergers and shakeouts. A takeover by DASA offered only a temporary solution to its financial problems, Fokker announced bankruptcy in 1996 (Heerkens and Ulijn, 1999).

---

[219] An interesting element of the competition between Fokker and Bombardier is that Shorts, the company acquired by Bombardier, was a component supplier of Fokker. Bombardier could thus learn from the negotiations with Fokker, already before introducing the *Canadair* regional jets, how crucial capacity was for competitiveness.

[220] BAe produced the *Jetstream* 41 and the *ATP*, Fokker the F-27 derivative F-50. The F-50 took off in 1985, serial production started in 1987; BAe's ATP entered production in 1988. The BAe Jetstream 41, a stretched version of the 1980s model entered the market in 1992.

[221] This unique design performed poorly due to its wide fuselage (increased drag) and weaker engines. Technology was evidently insufficiently advanced for an efficient and reliable RJ at the time of increasing fuel prices. The project was cancelled in 1977.

[222] Between 1985 and 1996, the Dutch currency fluctuated between 3.7 and 1.5 NLG to a USD with an overall declining trend.

DOI: 10.14267/phd.2016013

Interestingly, the British company Short Brothers also considered launching a radically new 48-seater jet, the *FJX* (Ramsden, 1989b). However, the *FJX* never progressed beyond the concept phase, after Bombardier, recognizing a potential supplier but also competitor, acquired the company in 1989. Other European smaller aircraft producers struggled in a lethal competition in the 1990s. Collaboration took place only for LCA in the framework of the Airbus consortium, which absorbed significant resources. Airbus, like Boeing, was uninterested in the more price-sensitive RJ market. Saab, despite its experience in producing turboprops and fighter jets, never decided to invest in developing RJs. Evidently, the low fuel prices came to the detriment of the turboprop market, which witnessed the exit of old European incumbents (Saab, BAe and Fokker), where only the Franco-Italian ATR consortium survived. Dornier, a Germany-based Fairchild subsidiary, recognized the opportunities and launched the Do-328JET by equipping its 30-seat turboprop with jet engines. But the aircraft entering in 1999 trailed its overseas competitors in performance and costs.[223]

The only other successful contender in the 50-seat RJ market was Embraer. The Brazilian state-owned enterprise already launched design in 1989, but was severely delayed by financial problems and the difficulty to find partners. Only after Embraer's privatization did the 50-seat ERJ-145 program take off, four years later than Bombardier's CRJ. Its early-1990s crisis gave a head-start to Bombardier, but Embraer quickly caught up thanks to the strong designand competitive price of the ERJ-145. This benefitted from public support to 22% of development costs and an interest rate equalization scheme (Goldstein, 2002a).Considering it illegal, Bombardier pushed the Canadian government to fight Brazil's financing practice at the WTO.

5.4.3 *Preconditions for Bombardier's leadership*

Bombardier benefitted in many ways from being located in Canada. Canada's sectoral innovation system in aerospace had accumulated a very strong knowledge base over the preceding decades. The National Research Council financed fundamental research since the 1950s, developed gas turbines and offered wind tunnel tests (Niosi, 2000).[224]

[223] Nevertheless, the Do-328JET remains the most significant European competitor in the RJ market, with 110 aircraft delivered.

[224] Niosi (2000) notes that the National Aeronautics Establishment of the NRC, created in 1958, operated the only wind tunnel of Canada and supported the design of all aircraft and engine models for over a decade, i.e. the De Havilland wing designs.

DOI: 10.14267/phd.2016013

Aerospace firms were among the largest Canadian R&D spenders with a revealed comparative advantage. The Montreal and Toronto clusters (hosting companies such as Bombardier, Bell Textron, Pratt & Whitney, and Honeywell) had a long history of competitive aircraft, parts and components (including engines) development and manufacturing, relying on highly skilled scientists and engineers (Niosi and Zhegu, 2005). Bombardier had access to resources of both the Canadian and US aerospace innovation systems, thanks to its subsidiaries and to the strong ties between the Canadian and US aerospace industries. Canadian firms have been eligible for US government contracts since 1959 and maintained intensive technology- and market-oriented global collaborations (Anderson, 1995, Niosi and Zhegu, 2010). Furthermore, Bombardier could draw from its own managerial experience on running complex organizations. Perhaps the best indicator for its technological capabilities and market knowledge is that Bombardier's subsidiaries had already delivered over 450 DHC commuter aircraft and over 200 *Canadair* business jets by 1990 (although none were market leaders). Its successful other business lines and the supportive regional and federal governments provided Bombardier with strong investment capacity. Canadian exporters could benefit from repayable loans of the Export Development Corporation (Goldstein and McGuire, 2004).

In the early 1990s, MDD, Boeing and Airbus also possessed the technological and financial capabilities to produce RJs – had they wanted to enter the market. BAe and Fokker, "entrapped", as described above, lacked necessary capital. Other companies lacked some crucial elements for preconditions. Russian companies inheriting the advanced Soviet technology base had to face brain-drain and institutional crisis of the sectoral innovation system in Russia. In Indonesia, IPTN, a co-producer and co-designer of turboprop transport aircraft lacked the experience to design, produce and market jets and could not draw on a well-established sectoral innovation system. Embraer had still to accumulate technological capabilities to produce a RJ, but struggled under the effect of the lingering effect of the financial crisis and the slow decision-making due to its state ownership (Frischtak, 1992). As a result, it neither had the financial capacity to launch a 50-seat jet, nor the capacity to enter into joint ventures to access missing technologies and funds – until its privatization in 1994.

DOI: 10.14267/phd.2016013

5.5 Embraer's leadership in the 70-120-seat segment (2005 –)

5.5.1 Windows of opportunity

Demand gradually shifted towards larger RJs by the late 1990s, due to increasing fuel prices (Figure 5.1) that started to question the viability of 50-seat jets. The increased competition with low-cost carriers forced traditional and regional airlines to be more sensitive to cost-efficiency. Airlines ordered modern turboprops or larger RJs with lower fuel consumption per seat. The regulatory cap also followed economic realities and scope clauses at major US airlines were re-negotiated from 50 to 70 seats, and beyond.[225] Major producers became optimistic about the prospects of the 100-seat segment. Boeing foresaw demand for 3,006 new aircraft until 2020[226] driven by income and population growth in emerging markets and by the need to replace aging narrow-bodies (B-727s and DC-9s) in America and Europe. Older models were more costly to operate, and states imposed stricter noise regulations.[227] Airlines also recognized the potential of reducing aircraft size to 100 from the typical 150-180 seat range to allow greater frequency direct services, and new city-pair connections (USITC, 1998).

Technological windows of opportunity for the RJ industry were probably less important for this period. Nevertheless, results of incremental improvements in jet engines, in avionics, in the diffusion of composite materials were becoming available industry-wide, at specialized second- and third-tier suppliers, altogether increasing efficiency. In parallel, improvements in the aviation infrastructure (in air navigation services, air traffic management) resulted in greater capacity to handle the growing air traffic and allow more economical operations.

Subsequently, market volatility (in the wake of 9/11 or the 2008 financial crisis) forced LCA operators in the 150-plus seat range to shift to smaller size, at a time when liquidity mattered. Larger RJs offered flexibility of greater frequency at times of boom, and a cheaper way to defend network spread when demand dropped. While low fuel prices and strict scope clauses offered an opportunity for 50-seat RJs in the 1990s, increasing fuel prices, market volatility and relaxed scope clauses opened a window for the 70-120-seat segment in the 2000s (Table 5.1).

---

[225] "Scope Clauses and New Regional Jets – A Coming Storm?" *AirInsight*, 3 May 2013

[226] Values refer to the 90-120-seat range (Boeing, 2001); Embraer's – probably strategically – more cautious forecast (Embraer, 2001) estimated 1,650 for the 91-120-seat range.

[227] In effect, banning old aircraft from operating in Western airspace. As a temporary alternative, some operators opted for noise reduction kits ("hush kits"), while others pushed manufacturers to re-engine existing models.

DOI: 10.14267/phd.2016013

5.5.2 Strategic response

Towards the turn of the millennium, the RJ industry was poised to become overcrowded, as European and American incumbents and Asian newcomers announced plans to re-engine existing models, resize existing models, or develop new designs (Doyle et al, 2000).

Embraer's winner strategic choice was a radical innovation. It recognized the emerging market niche already at the height of its ERJ-135/145 production cycle, and explicitly targeted the 70-110-seat market.[228] When launching the new E-Jet family, the company built on its 30-year experience in producing for the global commuter market, as well as on the experience from the risk-sharing partnerships already established during the mid-1990s. In a stronger position after the success of the ERJ-135/145 family, Embraer could reduce the number of partners to optimize costs, and attract some of them to Brazil. Embraer took a 45% stake in the E-Jet programme, while the rest were shared by the 16 partners (Figueiredo et al, 2008).[229] A few months after the launch of the E-Jets in 1999, 20% of Embraer's shares (with no voting rights) were sold to a group of French aerospace firms, EADS, Dassault Aviation, Thomson-CSF and Snecma. Embraer, with government backing, strategically selected the investors offering in exchange stronger perspectives for future fighter jet procurement and better access to the Latin American military market. As a direct implication of the change in ownership, Embraer implemented Dassault's state-of-the-art computer aided design and manufacturing systems, a powerful virtual reality platform for co-development, all of which offered significant flexibility improvement and cost reduction.[230] Although the E-jets were clean-sheet design, they shared in-family commonalities and some degree of commonalities with its predecessors to further reduce costs (Norris *et al*, 2004). A crucial source of efficiency gain was selecting an engine developed specifically for the

[228] It publicized the strategy as the "70/110 rule", see (Embraer, 2005)

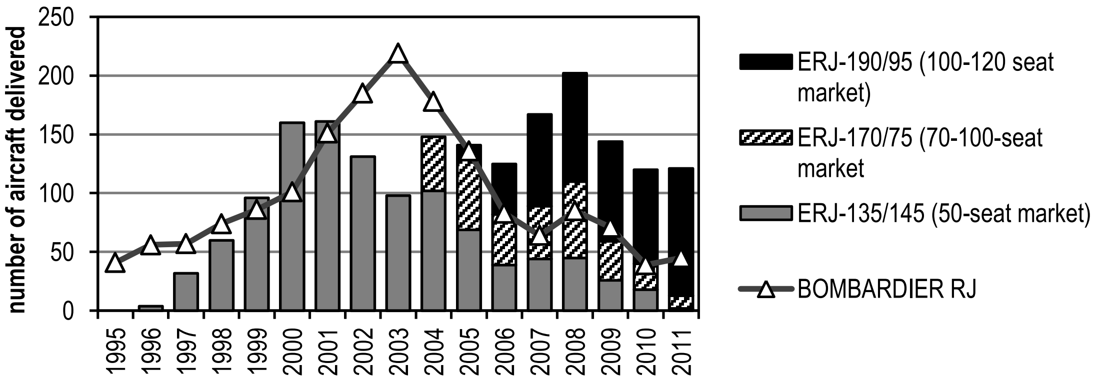
[229] Some of the main partners were GE, the single producer of engines (a package worth around 20% of the plane price), Honeywell (a GE subsidiary by now) responsible for avionics, Gamesa of Spain responsible for the tail section and rear fuselage. Liebherr supplied the landing gear and Kawasaki Heavy Industries of Japan was in charge of parts of the wing control surfaces made using composite materials and pylons, although this last collaboration did not go smoothly and was changed for "younger member" products of the family.

[230] For details on the strategic deal, see Moxon and Lewis, 1999; Autry, 1999; Cassiolato et al, 2002 and Goldstein, 2002a.

DOI: 10.14267/phd.2016013

E-Jets, (the General Electric CFM34-8E and -10E).[231] Embraer swiftly launched a full family of aircraft. The 80-seater ERJ-170 first flew in February 2002 and was certified and delivered to the launch customer two years later. A slightly stretched version with 88 seats, the ERJ-175 was introduced a year later, followed by the 110-seater ERJ-190 and the 122-seater ERJ-195, both with redesigned wings and greater engine thrust (Table 5.1). The American low-cost carrier JetBlue became the launch customer with an order of 99 and option for another 100 planes (Cameron, 2005). The E-Jets directly competed not only with the largest members of the BAe RJ100, but also with the smallest Airbus and Boeing models.[232] By 2005, Embraer overtook Bombardier in RJs delivery rate (Figure 5.7). The sources of competitiveness for Embraer's products were its sales and operating costs. Operating costs were low because the plane was specifically designed for this market. Lower labour costs in Brazil had only a limited effect on the prices[233], given the fact that Embraer aircraft are overwhelmingly (90%) produced outside Brazil (despite efforts to increase the local share). Publicly funded export credits played an important role in Embraer's success (although to a smaller degree after the settlement of the WTO dispute between Brazil and Canada).

Figure 5.7 Number and types of annual regional jet deliveries by Embraer in contrast with Bombardier



Source: Embraer and Bombardier Annual Reports.
Note: ERJ-170/175 served the 80-90-seat segment; ERJ-190/195 served the 100-120-seat market segment.

[231]. Introducing a new engine entails substantial R&D costs and time. Two features reduced time for the benefit of Embraer: both the commonalities this engine shared with the CFM34 family, and the fact that development was already launched for the abandoned Dornier 728 program (Norris, 2003).
[232] Despite speculations that the aim of a 1999 acquisition of 20% of Embraer's shares by European aerospace investors (including Airbus-owner EADS) was to limit its room for strategic manoeuvres, no evidence emerged to substantiate any hostility. Eventually, EADS, the owner of Airbus, sold its stake in 2007 (Done, 2007).
[233] Although a certain benefit when contrasted with the potential Bavaria-based competitor, Fairchild Dornier.

DOI: 10.14267/phd.2016013

Embraer also expanded production capacity. Along the original plant at the airport of Sao José dos Campos (near the research and training institutes CTA and ITA), it opened another site nearby in 2001, specializing in small parts development and engineering. This site also hosts an in-house, postgraduate school to train future aircraft designers. It also opened a new plant to assemble aircraft for the defense and executive markets. The most important aerospace cluster nevertheless remained Sao Jose dos Campos, home to most of Embraer's suppliers in the lower tiers, many of them spin-off of CTA or Embraer. With the primary aim to access the Chinese market, Embraer jointly opened with AVIC II an assembly facility for its outgoing product line in Harbin in 2002. By Apr 2012, 41 ERJ145's were produced here (Fleury and Fleury, 2011). The plan of Embraer to bring the E-190 assembly to China, was, however, rejected in order to protect the future market for the newly developed ARJ-21, although it did sell the type to various Chinese airlines. A 2011 agreement extended the production of the executive jet derivative of the ERJ145 in Harbin.[234]

The 70-120-seat jet market had several incumbents that failed to remain or become leaders. BAe re-engined and modernized the BAe-146 family in 1993 and marketed the Avro RJs with some success. However, high production and operating costs (owing to the four-engine design) put pressure on the company to make further improvements. BAe Systems[235] eventually made the less ambitious choice to again re-engine existing the Avro RJs (RJ-X), but the 30-year-old design received insufficient orders and the company exited the RJ industry in 2002 (Kingsley-Jones, 2006).[236] Boeing and Airbus also noticed the windows of opportunity for the 100-seat segment. They chose a cautious strategy to extend their existing families downward to reduce development and marketing costs. However, these aircraft were derivatives of planes optimized for the 150-180-seats size, and the one-family-fleet advantages offered to network carriers could not offset their relatively higher operating costs. Boeing tried to market two aircraft: the 117-seat B-717 it inherited from MDD, and the 737-600, the smallest member of the successful 737 family. Sales performance was mediocre for both models until Boeing de-listed them in 2006. Airbus offered the less successful A-318, the

[234] As a comparison, Bombardier's strategy was to manufacture parts of the Q400 and the CSeries aircraft in China, but realized fewer RJ sales than Embraer.
[235] The company formed with the merger of BAe and Marconi Electronic Systems in 1999
[236] Interesting to add, that the company re-focused its activities as defence producer and component supplier, and remained one of the largest aerospace firms.

DOI: 10.14267/phd.2016013

smallest member of the A-320 family for the same segment. A cautious attempt to co-develop a smaller aircraft together with Alenia, AVIC and Singapore Technologies Aerospace (the AE31x) failed due to insufficient capabilities of partners and concerns about technology transfer to China (Moxon and Lewis, 1998). Bombardier chose a similar strategy of incremental change to meet demand in the 70-100-seat class. It further stretched the CRJ700 to the -900 and -1000 models, until the limits of the original design. Bombardier was hesitant to address higher seat ranges with a radically new aircraft. In 2000, it shelved the billion-dollar “BRJ-X”, which was an order of magnitude higher than stretching the CRJs (Lewis, 2000). Besides the costs, Bombardier was unwilling to challenge the powerful incumbents in the large civil aircraft market segment. Only after Embraer introduced its new E-Jet series did Bombardier decide to revisit the idea. But the development of the radically new 100-150-seat CSeries RJ was severely delayed by technological challenges and lack of orders, and first flew only in 2013. In effect, due to the strategic choices of incumbents, Embraer became the sole producer for the 100-120-seat segment.

Five other challengers tried to launch a new design. Two of them, AVIC/Comac of China and IPTN/DSTP of Indonesia, lacked the necessary preconditions to develop a competitive RJ for the global market. Comac’s 100-seat ARJ-21 jet successfully took off in 2008 after prolonged development, but missing FAA certification limits its export potential. DSTP’s 2130 jet concept was abandoned as funds ran out (Vertesy, 2011). Fairchild Dornier, the small producer of 32-seat jets, turned out to be the most serious contender of the E-Jets. The radically new 728/928 family was developed to address the 70-110 seat range. Fairchild Dornier already constructed static test models and collected significant amount of orders by 2002 (Lewis, 2002). But the 9/11 crises intensified competition between Embraer and Dornier, and the Bavaria-based company, with low sales revenues, underestimated the development costs of the aircraft which would have underperformed the E-Jets, and filed for bankruptcy in 2002 (Kappl, 2002).[237] Ironically, both Embraer and Bombardier benefitted from taking over unsatisfied orders. In 2000, the Russian Sukhoi launched its *Superjet* (SSJ) program in collaboration with the Italian Alenia. After delays the first SSJ flew in 2008, and commercial operations started in 2011. With a seating capacity of 108, the largest SSJ (the SU-100/95) directly

[237] Many competitors, including Bombardier, considered taking over the company and continue the 728/928 development, but found the 1 billion dollars estimated cost of bringing the aircraft to market excessive, while the German or other governments did not show readiness to offer any support.

DOI: 10.14267/phd.2016013

competes with the E-Jets. Its initial sales were limited to the CIS market due to lack of trust, exacerbated by the crash of a demo flight in 2011 (Kramer, 2011). However, the recent European and American certification offers future growth potential.

5.5.3 Preconditions for Embraer's leadership

Embraer, the leading aerospace company of Brazil, gradually accumulated experience in the design, assembly and marketing of propeller-driven, pressurized regional-scale commercial aircraft and ground-attack jets since its foundation in 1969. Embraer built on Brazil's long history of aircraft production and aeronautical research. The publicly financed aeronautical research and training institute ITA and the technological research organization CTA were the backbone of the emerging Brazilian aerospace innovation system (Marques, 2004). Embraer, a CTA spinoff, has cultivated an entrepreneurial culture, but also benefitted from public support. This combination was crucial to overcome the technological and market barriers faced by a newcomer from an emerging economy. The government strategically financed development, access technology, protected the nascent market (by strategically selecting partners while excluding competition from others) and facilitated export market access (use diplomacy to speed up certification of new models) (Ramamurti, 1987; Silva, 2002). The CTA-designed *Bandeirante*, a 20-seat turboprop and its 30-seater upgrade, the *Brasilia*, became successful export products, of which a total of 500 and over 350 were produced over the 1970s-1980s, respectively. Embraer developed capabilities to design a jet trainer in the 1980s when cooperating with Alenia and Aermacchi. While the state-owned model worked for the emergence of Embraer, it became a burden after a political and financial crisis hit Brazil. In order to survive in the new competitive landscape, the industry had to be fundamentally reorganized (Frischtak, 1992, 1994; Cassiolato et al, 2002; Marques, 2004). The privatization of Embraer[238] in 1994 brought a major management overhaul for the company and a fundamental institutional change in the Brazilian aircraft innovation system (Vertesy and Szirmai 2010). Decision making became more efficient in the new private structure, as the company repositioned its core competence in co-design, system integration, sales and after-sales support. Embraer could access funding and advanced technology through risk sharing partnerships (Figueiredo, 2008)

[238] Buyers included Brazilian and US-based non-aerospace sector investors, while the government retained a golden share in Embraer.

DOI: 10.14267/phd.2016013

and attracting new shareholders, even if the domestic supply chain was weak. By the year 2000, the delivery rates of the ERJ-135/145 family exceeded that of Bombardier's comparable CRJ200, proving the success of the long-term catch-up strategy. The resulting revenue flows enabled Embraer to finance the development of the E-Jet family. Brazil's supportive industrial and export policy further facilitated global sales. For this, a one-billion-dollar credit line from the Brazilian Development Bank BNDES and the PROEX export financing scheme (offering interest rate equalization for buyers, subsequently challenged in the above-mentioned WTO dispute) proved instrumental.

Many of the other challenger companies failed to succeed to introduce 70-120 seat RJs due to missing preconditions. IPTN/DSTP lacked necessary resources to finance the development of a RJ, which would have also meant a major step from previous technological achievements; the Indonesian aerospace innovation system was underdeveloped (McKendrick, 1992). Despite seemingly abundant funding and access to foreign suppliers, the lack of prior experience in developing and marketing a commercial jet in China and the inefficient innovation system made the development process lengthy. Comac had to accumulate technological capabilities on the way, slowed down by the complex ownership and management structure (Vertesy, 2011). Fairchild Dornier possessed strong technological and management capabilities, and the German and US sectoral innovation systems were very strong. However, due to its location, the development costs exceeded the financial capacity of the company and its investors, and the Dornier received little targeted financial support from the German government.

5.6 Conclusions

Windows of opportunity and strategic response explain to a large extent why and how incumbents failed and challengers succeeded in taking leadership in RJ manufacturing. The case studies confirm that in addition, preconditions explain why so many challengers failed to become leaders. This section synthesizes the pattern of leadership change emerging from the case studies and how each of the three elements of the framework contributed to it. An outline of the key sources of leadership change is given in Table 5.2.

DOI: 10.14267/phd.2016013

5.6.1 Windows of Opportunity

We found all three types of windows of opportunity instrumental for leadership change. Challenger companies benefited from the availability of new technology on the market, such as more efficient engines than those used on existing models, and – typically incremental – improvements in aircraft systems. While incumbents (BAe as well as Bombardier) could also apply such improvements to upgrade existing products, there was a technological limit. Challenger companies had greater freedom to introduce combinations of technologies targeting specific market segments, resulting in efficiency gains over incumbents.

DOI: 10.14267/phd.2016013

Table 5.1 Technological and market performance of leading regional jets

Manufacturer (family)	Aircraft	RJ Market	Maximum seats	In serial production	Nr. Produced[a]	Maximum range[b] nm (km)	Turbofan Engine Type	Engine bypass ratio	Max. cruise speed Mach (km/h)	Cabin Width (m)
British Aerospace / BAe Systems (BAe-146 fam.)	**BAe-146-100**	70/120-seat	94	1983-1992	35	1,620 nm (3,000 km)	4 x Textron Lycoming ALF 502R	5.7:1	M 0.72 (760 km / h)	3.42 m
	BAe-146-200		112	1983-1993	98	1,600 nm (2,963 km)			M 0.72 (760 km / h)	3.42 m
	BAe-146-300		128	1988-1998	60	1,520 nm (2,817 km)			M 0.72 (760 km / h)	3.42 m
BAe/Avro (RJ70/100 fam.)	**RJ70**		94	1993-1996	12	1,660 nm (3,075 km)	4 x Honeywell LF-507	5.3:1	M 0.73 (788 km/h)	3.42 m
	RJ85		112	1993-2002	87	1,780 nm (3,295 km)			M 0.73 (788 km/h)	3.42 m
	RJ100		118	1999-2002	71	1,780 nm (3,295 km)			M 0.73 (788 km/h)	3.42 m
Fokker (F70/100 fam.)	**F-100**	70/120-seat	122	1988-1996	276	1,450 nm (2,685 km)	2 x Rolls Royce RB.183 Tay	3.04:1	M 0.77 (844 km/h)	3.1 m
	F-70		85	1995-1997	45	1,780 nm (3,295 km)			M 0.77 (844 km/h)	3.1 m
Bombardier (CRJ fam.)	**CRJ200**	50-seat	50	1992-	1,100	1,585 nm (2,936 km)	2 x General Electric CF34-3B	6.2:1	M 0.81 (860 km/h)	2.53 m
	CRJ700	70/120-seat	78	2001-	331	1,504 nm (2,785 km)	2 x General Electric CF34-8C	5:1	M 0.85 (876 km/h)	2.57 m
	CRJ900	70/120-seat	90	2003-	274	1,515 nm (2,806 km)			M 0.83 (885 km/h)	2.57 m
	CRJ1000	70/120-seat	104	2010-	19	1,622 nm (3,004 km)			M 0.82 (870 km/h)	2.57 m
Embraer (E145 fam.)	**ERJ-145**	50-seat	50	1996-	701	2,000 nm (3,706 km)	Rolls-Royce AE 3007-A1	5:1	M 0.78 (830 km/h)	2.10 m
	ERJ-135	30/50-seat	37	1999-	108	1,750 nm (3,243 km)			M 0.78 (830 km/h)	2.10 m
	ERJ-140	30/50-seat	44	2001-	74	1,650 nm (3,058 km)			M 0.78 (830 km/h)	2.10 m
Embraer (E-Jet fam.)	**ERJ-170**	70/120-seat	80	2004-	178	2,100 nm (3,889 km)	2 x General Electric CF34-8E	5:1	M 0.82 (870 km/h)	2.74 m
	ERJ-175	70/120-seat	88	2005-	143	2,000 nm (3,706 km)			M 0.82 (870 km/h)	2.74 m
	ERJ-190	70/120-seat	114	2005-	386	2,400 nm (4,448 km)	2 x General Electric CF34-10E	5:1	M 0.82 (870 km/h)	2.74 m
	ERJ-195	70/120-seat	122	2006-	88	2,200 nm (4,077 km)			M 0.82 (870 km/h)	2.74 m

Source: Own compilation based on manufacturers' website, airliners.net and flightglobal.com
Notes: (a) Nr. produced by Dec 2011; commercial variants only, figures exclude business, cargo and defense derivatives; (b) for long range variants

DOI: 10.14267/phd.2016013

Table 5.2 Key drivers of leadership change: preconditions, windows of opportunity and leading products

	Window of Opportunity			**New Leader (other challengers – type of design[a])**	
Preconditions	**Technology**	**Demand**	**Regulatory**		**Leading product**
Bombardier's leadership in the 50-seat RJ market					
• Advanced Canadian aerospace innovation system; • Bombardier predecessor companies' technological capabilities	• more efficient engine (5:1 bypass ratio) • diffusion of ICTs	• US: hub-and-spoke system; competition of hubs; congestion • EUR: liberalization, integration • Low oil prices • preference for jets over turboprops	• Scope clauses capping the 50-seat market	• Bombardier – Rad. • (Embraer – Rad.) • (Dornier – Incr.) • (Shorts – Rad.)	• Bombardier CRJ200 and CRJ family, leader in the 50-90-seat market
Embraer's leadership in the 70-120 seat RJ market					
• Brazilian aerospace innovation system; • Embraer's privatization and experience in commutes and regional jets	• improvements in engines, avionics, materials; as well as in aviation infrastructure	• increasing oil prices, • replacement of aging narrow-body jets • fluctuations in world economy	• scope clauses relaxed; • environmental regulations	• Embraer – Rad. 6. • (BAe – Incr.) • (Boeing – Incr.) • (Airbus – Incr.) • (Bombardier – Incr.) • (Fairchild-Dornier – Rad.)	• Embraer "E-Jet" family (ERJ-170/190), leader in the 90-120-seat market

Note: a) Type of design: Incr. = incremental improvements in existing design; Rad. = radically new clean-sheet design

DOI: 10.14267/phd.2016013

Changing trends in fuel prices created the most important demand windows. The declining trend of the 1990s boosted demand for 50-seat RJs; the subsequent increase in oil prices opened a window for 100-120-seat RJs. This exogenous factor demonstrates how leadership depended on chance. The company with the closest bet on the future of fuel prices became the leader. Business cycles played an equally important role. Economic growth in the mid-1990s and mid-2000s up to 2008 was fundamental to boost demand for RJs that were already in serial production. For challengers to become leaders, a delicate combination of changes in demand appeared necessary, confirming but qualifying the findings of Mathews (2005) and Lee and Mathews (2012). Upturns and expectations of growth secured sufficient investment to start new product development. Downturn around the time of product launch (in the first half of the 1990s and after 2001) cleaned the market for the benefit of the most efficient challenger. Downturns also allowed a head-start to the best challenger (i.e. Bombardier over Embraer in the early 1990s, and Embraer over Fairchild-Dornier or Sukhoi in the early 2000s).

Among the many regulatory windows, two proved particularly important for leadership change. The first type was the introduction and relaxation of “scope clauses”, or internal airline agreements that created clear opportunities for RJs against LCAs. These regulations were typically exogenous to aircraft producers’ strategies. The other main type of regulation were government policies such as loans to support new aircraft development, export financing regime, and the changing public ownership of a company, proved beneficial for both new leaders. Many of these were “endogenous” windows, showing signs of strategic collaboration between companies and their host governments, securing temporary protective space for the emergence of leading products. Conversely, insufficient regulatory windows may have exacerbated the difficulties of failed incumbents and challengers, i.e. Fokker or Dornier. Some regulatory windows affected demand in asymmetrical ways. For instance, both incumbents and challengers benefitted from the liberalization of the air transport market in the US and Europe. This was not the case with China, where access was provided in exchange for technological or economic benefits. Yet, this specific regulation does not appear to have affected leadership change. While outside the scope of this paper, it would certainly be interesting to estimate the net costs of various interventions in a future study.

Leadership change necessitated not only the right kind of combination of windows of opportunity, but also their right timing. As expected, the timing and duration of windows were important to ensure that challengers could find a market niche, recover sunk costs, and have limited competition. This of course depended also on sufficiently swift response.

DOI: 10.14267/phd.2016013

5.6.2 *Strategic response*

We distinguished innovation strategies from longer term catch-up strategies to better compare incumbents' and challengers' responses to emerging windows of opportunity. As presumed, new leaders relied on the strategy of launching new aircraft families while incumbents opted for extending the product ranges of existing families. Launching a radical innovation (the CRJ family) to target the 50-seats niche market paid off for Bombardier as the smallest products of the incumbents were around 40% larger, thus less economical. Similarly, Embraer's E-Jets had virtually no competition in the 100-120-seat niche due to the incremental innovation strategy of incumbents. The common pattern in new leaders' strategic response was the introduction of technologically superior products, produced more efficiently. They relied on specialized core competences, such as design, system assembly, sales and after-sales support activities, and risk-sharing partnerships. Their main product and organizational innovations were new to the RJ market but not necessarily new to the world: LCA producers have already applied similar technologies, and their producers implemented organizational innovations. In this sense, leading companies were "strategic followers" (Mathews, 2005), scaling down existing technology within an existing architecture (Christensen, 1997).

The successful challengers reduced the higher cost of new product development in various ways. Both Bombardier and Embraer relied on the existing technology (the *Canadair Challenger* business jet for the CRJs and to a less extent on the ERJ-145 family for the E-Jets), government support, and on risk-sharing partnerships. Both Bombardier and Embraer applied the family concept, and extended their product range by introducing highly similar aircraft with different seating capacity or engine performance (see Table 1). Variety creation allowed companies to exploit the evolving demand, confirming the findings of Frenken *et al* (1999). "Leading products" were crucial for market leadership. Over the past 30 years, leading products were tailored to meetdemand shifting from the 70-100-seat to the 50-seat and back to the 70-120-seat market, in response to changing oil prices and competition with turboprops and LCA.

Incumbents faced substantial uncertainty, due to changing oil prices and recurrent crises, rather than other factors.[239] Resizing or upgrading existing products in order to recover sunk

---

[239] The following quote of Bombardier's CEO offers a good illustration: "Asked to predict when struggling Bombardier will return to financial strength, […] Paul Tellier challenged the questioner: 'Tell me how long it is going to take for the airlines to get back on their feet, where the Canadian dollar will be, where the oil price will be, and I will tell you when.' " (Warwick, 2004)

DOI: 10.14267/phd.2016013

costs and diversify product portfolio was a rational strategy. For instance, BAe extended its RJ production and sold 170 Avro RJs under less favourable market conditions after 1993. However, it could not sustain leadership or generate sufficient funds to develop newer models. Similarly, Bombardier's strategy not to develop a new aircraft was difficult to challenge, particularly around the 9/11 downturn. Incumbents were trapped by their struggle to recover sunk costs and lock-in to production arrangements with low profit margins (Lee and Malerba, 2013). They could not launch radical innovations, and were vulnerable to disruptive innovations by new challengers (Abernathy and Clark, 1985; Christensen, 1997). The effect of incumbent traps is more dramatic considering that product life cycles were linked to competitiveness (Klepper, 1996). Thus, unless incumbents started to develop a new family at the declining phase of their leading product's life cycle were at risk of exiting the industry.

Uncertainty can also affect the timing of response. Firms that waited too long to respond to emerging windows were also trapped by the long lead-time, if the relevant windows closed before the product they invested in could reach the break-even point. The Do-328Jet offers a good example. In any case, firms need luck and foresight ability to judge how long windows of opportunity will be available.

Alongside companies, governments were confirmed to be strategic actors in innovation systems. The question is not whether governments intervened for leadership change, but how and when. They have effectively modified windows of opportunity by strategically applied interventions, such as standard setting, selection of trading partners, granting market access in return for access to technology. Efficient "public-private coalitions" appear to have supported successful challengers. At the time of product launch, direct or indirect public financial support helped new entrants reduce risks.[240] Bombardier received export credits while Embraer's buyers had access to interest-rate equalization mechanism. Furthermore, Embraer traded the promise of better positions for military procurement in exchange for finding investors providing it with finance and technology for the E-Jets. There are two interesting lessons from the roles of the Brazilian and Canadian governments. First, that effective support can help mitigate the effects of a missed window of opportunity. Although Embraer's ERJ-135/145 entered the market after Bombardier's CRJs, it quickly caught up in terms of delivery rates. Second, governments have political tools to defend incumbents, such as

[240] Government loans are (up to a third of the development costs) even compatible with international trade law. See i.e. the 1992 EU – US Agreement on Large Civil Aircraft; the applicability of this agreement to RJs is debated.

DOI: 10.14267/phd.2016013

fighting "trade wars" with retaliatory measures. Yet, the Canada-Brazil trade dispute did not prevent subsequent leadership change, especially after both parties were found in breach of international trade law (see Doh, 2003, Goldstein and McGuire, 2004). The room for government interventions is further limited by macroeconomic conditions or domestic politics, as shown by the reluctance of the Dutch government to bail-out Fokker in 1996 or the inability of Brazil to finance Embraer in the early 1990s.

5.6.3 Preconditions

Both successful challengers were experienced aircraft producers when they responded to the relevant windows of opportunity. Their salient product innovations that triggered leadership change were of competence-enhancing, rather than competence-destroying nature for the companies, confirming the findings of Tushman and Anderson (1986). Thus, accumulated technological capabilities mattered for leadership in the RJ industry.

The two leaders have successfully implemented a long-term catch-up strategy, and have already climbed the steep initial learning curve. Looking at the company's trajectory may be misleading in the case of Bombardier. While at first it seems to have followed a special leap-frogging strategy (Lee and Lim, 2001) by rapidly accumulating technological capabilities through the various companies it acquired. But from the perspective of the Canadian aircraft industry, the path is more gradual: RJs are a continuation of turboprop commuter and business jet production. Embraer and Brazil also gradually and systematically built up the knowledge and skills necessary to produce and market small aircraft. Both companies possessed absorptive capacity to apply existing aerospace technology for RJs. Explicitly or implicitly, the long-term catch-up strategy involved collaboration between dominant firms and their host governments.

The advanced state of the sectoral aerospace industry in Canada and Brazil allowed companies to effectively respond to emerging windows. Companies could draw upon available resources, including skilled researchers, engineers and managers, public research organizations, and make use of institutions that facilitated interactions with internal and external actors. The successful long-term catch-up of a Brazilian firm highlights the role of government investment in the innovation system. It created preconditions for growth by training scientists and engineers in ITA, performing public R&D at CTA, providing a favourable business environment and access to external finance and technology. Canada has similarly been investing in the innovation system since the 1950s. At the same time, both sectoral innovation systems were open enough to supplement missing local technology with

DOI: 10.14267/phd.2016013

foreign sources. With risk-sharing partnerships, top-tier firms indirectly benefitted from government support provided to second-tier component supplier. Furthermore, active links with buyers in key export markets provided firms with the knowledge to identify niches. Conversely, where the knowledge base was insufficient or where innovation systems underperformed due to institutional hurdles – i.e., in Indonesia, Russia or China –, companies were not in the position to implement optimal strategies. Moreover, AVIC/Comac and Sukhoi lacked the experience to design, certify and sell aircraft, and could not respond faster than Embraer when the opportunity emerged. The difficulty of the apparently abundantly financed AVIC/Comac to exploit windows of opportunity provides a crucial message on the limits to complementarity between different types of preconditions. Evidently, strong financial capability cannot replace missing technological capabilities.

The capacity to finance new product development proved to be another precondition in this capital-intensive sector. Not only strategic choices or incumbent traps, but institutional barriers to raise sufficient investment resulted in the downfall of Fokker and Dornier, and the delays of Embraer in the 1990s. This had deeper macro-economic roots, such as exchange rate volatility.

DOI: 10.14267/phd.2016013

Chapter 6: Conclusions: Schumpeterian dynamics in the aircraft industry

6.1 The three types of cycles and the evolutionary challenge

We have observed three distinct forms of cycles that affect the growth and decline of the aircraft manufacturing industry. First, at the level of products, the fortune of companies at the top of the pyramid depends on the sales performance of an aircraft or aircraft family. Sales success is not only necessary to recover the sunk costs in development, machinery, marketing and support activities, but also to enable companies to make further investments in new product development. **Production curves** can be extended if companies introduce refurbished products and modernize components and subsystems, such as replacing engines with more efficient ones. This pattern is applicable to large civil aircraft and regional aircraft alike, and affects the supply chain.

Second, at the **aggregate level of the aircraft industry**, we have identified cycles of expansion and contraction, which are closely correlated with business cycles in the world economy and affected by global political events. The oil crises, the increased defense spending during the last decade of the Cold War, the subsequent Gulf War, the 9/11 shock and the most recent global financial crisis are a few key events that made their mark on the evolution of the industry.

Thirdly, between these two levels, we have observed **discontinuities in the evolution of aerospace innovation systems**. Institutions in innovation systems govern learning, technological capability building and new knowledge production activities. Recurrent events of radical institutional changes that redesign the system and incremental change as actors gradually expand their activities within the system framework create a third type of cycles – albeit cycles that can only be observed indirectly.

Recurrent down-cycles and periods of reorganization are particularly interesting phenomena for the evolution of the aircraft industry, as they constitute at the same time a **risk for the survival** of industry actors, and offer unique **historical opportunities** for incumbents as well as new entrants to radically change their competitive positions. These moments would be textbook cases of turbulence, industrial reorganization, periods of mergers and acquisitions, which result in a change in the competitive landscape fostered by "creative destruction" – described as Schumpeter Mark I structure (Nelson and Winter, 1982 and

DOI: 10.14267/phd.2016013

Malerba and Orsenigo, 1996). Periods of crises come in very different size and shape, and only some of these will become real moments of creative destruction, but may trigger different behavior on behalf of system actors, and have multiple consequences. Yet, conversely, the cycles are created by the very behavior of system actors. In the following subsections, we elaborate on these interactive mechanisms by re-visiting the three research questions.

6.2 Riding the second wave of internationalization

The first research addressed the changes in the international division of labor in the aircraft industry, and the main patterns of internationalization. In chapter 2, we have found that the overwhelming majority of commercial aircraft exports, final products as well as intermediate goods, continues to originate from North America and Europe. Their combined exports have more than quadrupled in real terms in the past three decades. The double-digit annual average growth since 1990 which characterises emerging producers is to some part due to the very low initial levels, and also to their gradually increasing production capacity. A more noticeable global trend has been a gradual redistribution of exports between the US and Europe. At the same time, it is important to note that in 2012, two emerging exporters made it to the top 10: Singapore and Brazil, with market shares comparable to that of Japan, Italy or Spain.

Considering the domestic market as well and focusing on value added, we find a more significant global redistribution in the mid-ranks of the top 10 aircraft producers. While the dominant producer by far remains the US (producing more than 2.6 times the amount of the 9 subsequent countries), China has emerged as the second largest aircraft producer by 2010.

We have also noticed a redistribution of R&D activities. The largest business R&D spender in the aerospace industry continue to be the incumbents in the US, Europe and Canada, we have seen the rapid growth of China (today the 5th largest R&D spender) and the gradual growth of India and Brazil and Singapore.

We distinguished two waves of internationalization in which the aircraft industry extended to emerging economies. Although identifying them requires a certain degree of abstraction and the waves, in a few cases overlap, there have been notable differences between the two, as summarized in Table 2.3. We have seen that entry during the second wave of internationalization, occurring in an era when companies are increasingly specialized along the supply chain (most markedly since the 1990s), new entrants face lower capital and technology barriers than those entering over the 1950s through the 70s, in an era of vertically

DOI: 10.14267/phd.2016013

integrated companies. Therefore, it is not surprising that among the many entrants, the success of Embraer was exceptional. Today, internationalization is fuelled by the pull-force stemming from the shared strategic interests of governments of emerging economies and of incumbent firms in the West. The goals of governments of emerging economies for establishing high-tech, high value added activities and move up along the value chain – national security interests notwithstanding – meet with the company interests in cost saving and access to growth markets. Containing this wave creates a particular challenge for established players in Europe and North America, which fear the loss of high value added jobs. Yet, the scale of threat has not yet been justified; consolidation (mergers and acquisitions), efficiency gains through the use of ICT and reduction in defense spending appear to have been the major source of aerospace jobs reduction in the US and Europe, rather than outsourcing to East Asia. The global aircraft manufacturing industry is still concentrated to North America and Europe (around almost 88% in terms of value added) and faces and expanding market – thus, contrary to what hawks say, it is not a zero-sum game. But comparing the two waves of internationalization, the second one is expected to have more profound effect then the first. While statistics show that the fears of North America losing positions may be exaggerated, European countries face a more direct challenge and need to improve significantly their competitiveness in aircraft manufacturing, attract R&D and high value-added jobs, particularly in niche activities. In the end, innovation systems compete to attract investors, and the number of potential locations has certainly increased – mostly in East and Southeast Asia, Central America, and potentially, Central Eastern Europe. Yet, there are significant limits to internationalization, as capabilities cannot be accumulated overnight, which require not only advanced training of highly-skilled professionals, but also other modes of less formal learning, i.e. ‘learning by doing’. Thus, barriers for latecomer entry remain high, as aerospace manufacturing remains a technology and capital intensive industry

.

6.3 Success and failure in catch-up

6.3.1 Latecomer performance and evidence of catch-up in the first wave

In order to answer the question why some countries succeeded while others failed to catch-up in aircraft manufacturing, we need to qualify the concept of ‘catch-up’. If catch-up is defined in a strict sense (closing the gap or forging ahead of the leader in labor productivity), only

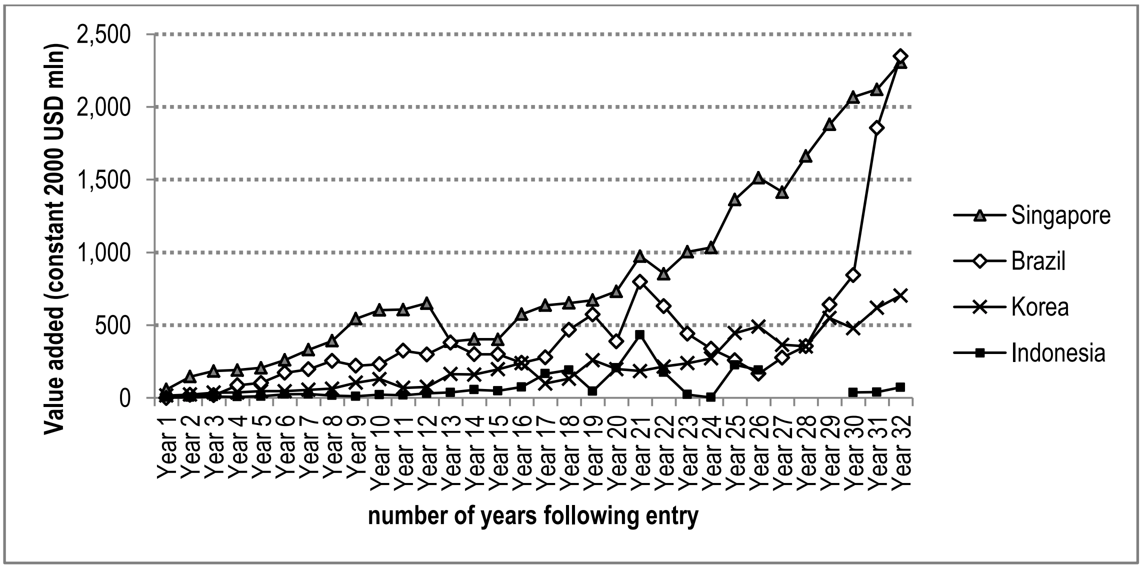
Singapore and Brazil have succeeded in forging ahead of the US, and only for limited periods. In a more relaxed sense, three emerging aerospace producers, China, Brazil and Singapore have approached and in some cases, outperformed leading OECD countries in terms of value added in aerospace. In terms of growth acceleration, Indonesia, South Korea and Mexico (alongside the above-mentioned countries) have experienced sustained periods of faster-than-the-leader growth. Yet, if considering emerging economies as a group, their share in global output remains small, making aerospace one of the few sectors where industrialized economies hold an exceptionally large global market share. If the process of catch-up is defined as an increase in relative value added share, we have a number of cases of catch up on the basis of which we can draw conclusions concerning the nature of the catch up process.

During the first wave of internationalization, four newly industrializing economies decided to establish aircraft manufacturing capabilities in their countries: Brazil, South Korea, Indonesia and Singapore. We can compare their success in terms of value added growth with regards to year 1, as shown in Figure 6.1 in order to compare the development trajectories. Evidently, Singapore and Brazil achieved significantly greater growth than South Korea and Indonesia. But even in the case of the stronger performers, growth was not continuous.

Figure 6.2 shows evidence for the second wave of internationalization from the perspective of emerging economies. By charting the growth in exports that are accounted for as intermediate inputs for aircraft industry outputs in destination countries, we can see how the share of these nine selected countries grew in the global aerospace value chain from 2 to 20% over two decades. This growth is impressive even if we disregard the logistics hub effect of Singapore. This growth can also be seen as a catch-up trend with regards to the top performer US.

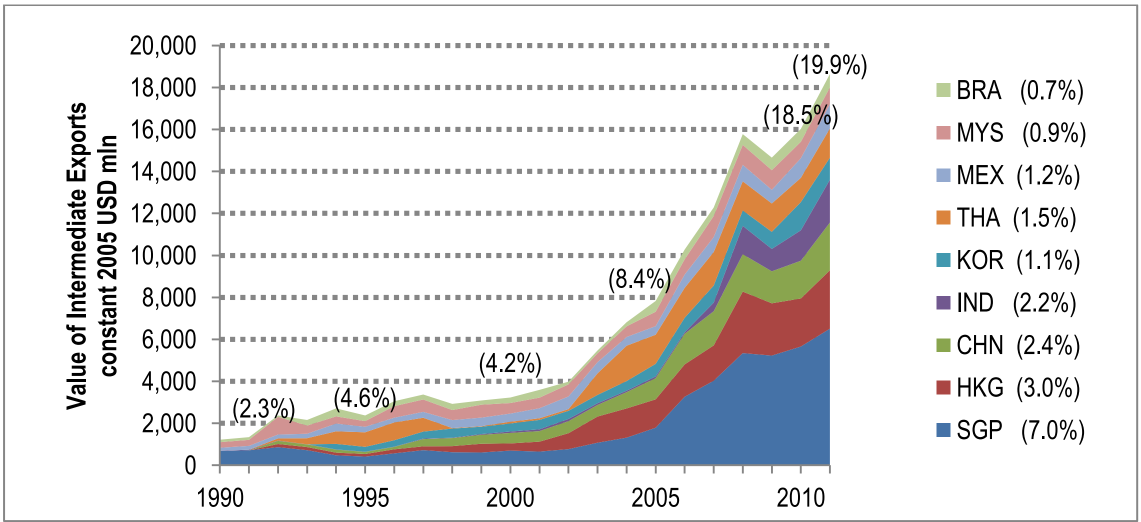
DOI: 10.14267/phd.2016013

Figure 6.1 Parallel evolution of the emerging aircraft industries in 4 selected countries



Source: Vertesy (2011) based on UNIDO, Embraer, GGDC, Hill and Pang (1988)
Notes: Year 1 refers to the start of dedicated industrial development programs (Brazil: 1969; South Korea and Indonesia: 1976; Singapore 1977).

Figure 6.2 Top emerging intermediate exporters (with share in world intermediate exports, %)



Source: OECD STAN Bilateral Trade Database by Industry and End-use category

We see that while that while the country growth trajectories look rather unique, many of the policies the four countries of the first wave chose to follow were similar. They all provided massive public financial support to the industry; sourced advanced technology by assembling aircraft under licenses. The air forces played a crucial role in all countries, often by providing facilities or creating demand for the locally assembled aircraft or financing by initial launch orders. Many of them made some limited modifications to existing models. A crucial distinguishing factor between the four country strategies was the early focus on commercialization in Singapore and Brazil and a strategy to sell in developed markets. In

DOI: 10.14267/phd.2016013

other words, technology push strategy complemented the demand pull. One can already recognize the differences by the second half of the first decade after the launch of activities. Sales to civilian markets were not only sources of additional finance for technological learning, but also provided incentives to increase quality and efficiency. The differences in product portfolios are also interesting. Singapore chose to be an MRO hub and a parts supplier, while Brazil chose to sell commuter aircraft. By the end of the first decade the strategy of Singapore proved to be more successful. Although Brazil did catch up in the long run, the MRO and parts and components production allowed for a more stable growth path in Singapore. Of course, Singapore's aggregate macroeconomic performance was much more stable than that of Brazil. Nevertheless, we concluded earlier that crises may represent windows of opportunity for adjusting strategies. In fact, we can identify recurrent crises in latecomer economies also in Figure 6.1. However this figure does not provide explanations for the large variation in the timing, length and depth of crisis periods in different countries. In what follows, we revisit the question of what strategies governments followed in emerging economies that fostered sustained growth in the sector – by looking at interruptions in the emergence and growth of the sector.

6.3.2 Interruptions as windows of opportunity

We found evidence of interruptions in the growth of the industry in all country cases studied in Chapter 4. The Brazilian aircraft industry underwent a crisis between 1990 and 1994; in Singapore between 1989 and 1991, China experienced shocks in 1961 and troubles from 1984 through 1996; in the case of Argentina, during the 1950s and after 1983, while Indonesia became a victim of the 1997 crisis. In Singapore a 40% decline in value added in a single year was followed by hardly any growth in the next two years before growth resumed at 43% in the subsequent year. Brazil experienced a 27% average decline of output for four years running and a 67% growth in the subsequent year. From 1984 to 1989 the Chinese aerospace output declined on average by 10% per year, grew by 12% for one year (1990), but then continued on a downhill course with a 6% decline for six years. Between 1997 and 1999 Indonesia experienced an average 76% decline in output. The decline was similarly dramatic for Argentina. The industry was performing relatively well in Brazil and Singapore prior to the crises (both with average value added of around 600 million dollars in the three preceding years) but it was also doing rather well in Indonesia (the three-year average was 230 million dollars) compared its earlier performance.

DOI: 10.14267/phd.2016013

A combination of macroeconomic, political and industry-specific factors was behind most of the crises. Declines in domestic and foreign demand, a drop in public financing, a lack of new product sales and a loss of competitiveness associated with aging technological capabilities were found to be potential triggering factors. Macro-economic events such as the Latin American and Asian financial crises or global recessions can explain the timing of interruptions, but they cannot explain their depth and length. Although these are factors external[241] to company management, we argue that recurrent crises are typical for the aircraft manufacturing industry. Companies and governments need to respond to crises to secure the long-term survival of the industry – which is why we consider them windows of opportunity.

Our historical studies showed that many instances of crisis not only affected the productive, but also the innovative activities. Given that innovation (together with learning and capability accumulation) was a systemic activity involving a multitude of inter-related actors, certain crises had a major effect on the entire system. We had earlier proposed to call this a pattern of interrupted innovation (Vertesy and Szirmai, 2010). Countries narrowing the technology gaps with the lead countries did not simply accumulate capabilities in an incremental fashion (as suggested by some of the catch up theories). Rather, the accumulation of capabilities was a process which was repeatedly interrupted by external macroeconomic and political crises and changing market conditions. Radical transitions in sectoral innovation systems were followed by periods of industry growth and more incremental changes in size and nature of the innovation systems. These transitions entailed a reconfiguration of the routines, rules and norms governing the interactions among existing and new actors in a catching up system, in line with demands and requirements of changing market conditions.

Our empirical evidence shows that sustained growth in latecomer aerospace industries is not possible without substantial changes in the aerospace innovation system in the country. The literature on sectoral innovation systems has emphasized the sector-specific co-evolution of “technology, demand, knowledge base, learning processes, firms, non-firm organizations and institutions” (Malerba and Mani 2009, p.11). But it has remained less articulate about the actual patterns of such co-evolution. While the industry co-evolves with technological change and macroeconomic and political events, this does not happen in a smooth incremental fashion. It co-evolves in a series of distinct cycles, interrupted by major crises and transitions. The cyclical changes in the performance of the sectoral innovation systems are closely linked to cyclical swings in the “real” industry.

[241] Although, as in the case of Indonesia for instance, the continued support of prestige aircraft development projects was a cause for instabilities.

DOI: 10.14267/phd.2016013

It is not straight-forward how to measure the size and performance of innovation systems, how to quantify qualitative changes and how to contrast actual performance with the *potential maximum* performance. The qualitative and institutional changes in particular, which occur over time, it is not possible to devise quantitative input and output measures of sectoral innovation system over a long time period.[242] We note that estimating innovation system performance frontier curves has never been the aim of this research, rather to offer an analytical framework for the case studies and complement it with limited empirical data to identify trend breaks. Long-run changes in innovation inputs (R&D expenditures, R&D/sales ratios, technology licensing, number of graduates in aeronautics programs, trends in foreigners' local patenting) and output indicators (such as new product sales or composition of exports) chart the trajectories and reveal interruptions and periods of transition. Trends in production system indicators such as value added and productivity were also used to identify interruptions and historical events as turning points.

6.3.3 Exogenous vs. endogenous windows of opportunity

In order to understand the behavior of key actors, it is important to establish whether the sources of interruptions were exogenous or endogenous to the system. Evidence from the case studies shows that innovation system changes are not triggered by internal factors – gsuch as a slowdown of innovation dynamism as the innovation system comes close to its innovation performance frontier, or by radical domestic innovations at the frontier. We found that exogenous demand shocks were behind most of the interruptions. Falling sales revenues, depletion of funding (public or otherwise), resulted in a drying up of resources available for innovation and thus losing competitiveness. At the same time, demand shocks also implied a qualitative shift in demand, and even if endogenous technologies were not available, in successful cases, systems could adapt to reach out to new technologies – which in turn offered windows of opportunity for latecomers to catch up, given that they did not have to finance the development of the given technology.

In fact, we found that radically new technologies did not originate from within a latecomer industry but could still revolutionize the industrial structure. None of the countries we examined introduced technologies new to the world, rather, it was either new components and systems (i.e., engines) or changes in the organization of production (the increased use of

[242] We have presented in the tables and figures of the case studies most of what is publicly available on innovation in latecomer aerospace industries. Greater transparency would certainly benefit any future research.

DOI: 10.14267/phd.2016013

hierarchical global supply chains by American and European producers) that triggered changes in Brazil and China (i.e., the risk sharing partnership model and the new strategy of joining global value chains, respectively).

Economic and political events external to the industry have represented another important type of window of opportunity. The role of government, either as investor, customer or technology provider is crucial in the case of latecomers as well as industry leaders. Such events were the Sino-Soviet split or the gradual market reforms in China, the strengthening of the military regime in Brazil and the financial crisis that ended it, similarly the fall of the Peronist regime in Argentina, or the Asian financial crises of 1997 in the case of Indonesia. But macroeconomic shocks do not necessarily result in system change – as the case of Singapore testifies. The effects of a crisis in the economy in 1985 and in 1997 were relatively limited for the aircraft industry and the decline from 1988 to 1989 was halted within one year. We noticed that the national innovation system was resilient enough, and continued to provide key resources (human capital, re-training and incentives for investment into innovation) in a speedy manner – even in what could be considered as a counter-cyclical policy. If the system is weaker or underdeveloped, not only are chances for interruptions higher, but the ability of system actors to devise a change strategy is significantly lower. We will revisit the behavior of key system actors below; but first we discuss why the emergence of a sectoral innovation system was crucial for the success of latecomer aircraft industries.

6.3.4 The crucial role innovation systems in latecomer aircraft industries

Surprising it may sound, but the aircraft industry is present in practically all countries of the world that have an airport, as most airports offer aircraft repair and servicing (MRO) activities. We distinguished this from larger scale production (or even large-scale MRO) activities, which necessitate a stronger presence of technological capabilities. Considering this latter group of countries, we found that none of them achieved accelerated growth in aerospace unless they developed local educational, training and research institutes, and dedicated policies to facilitate aerospace knowledge assimilation, generation and diffusion. Given that aerospace is a technology intensive industry, it is not surprising that a full-fledged innovation system is crucial for successful latecomer entry. At the same time, weak, enclave-type structures are typical for developing country innovation systems (Banji 2006), with weak links between buyers and suppliers, or between R&D institutes and relevant universities (if they exist at all). In weak national innovation systems, missing elements can rarely be replaced by establishing stronger ties with advanced countries. The cases of Argentina, China

DOI: 10.14267/phd.2016013

and Indonesia offer good examples. The jet fighter development during the late 1940s and 50s in Argentina was actually a spin-off of the German sectoral innovation system and was not linked to the development of local capabilities. The project eventually collapsed and the industry had to struggle to survive. Similarly in China, jet fighter production came to years of standstill after the Sino-Soviet split in 1961 due to the departure of Soviet experts and technicians. In Indonesia, indigenous aircraft development projects were frozen as a result of a weak innovation system in the late 1990s. In many of the cases these ‘enclave projects’ did show increased innovative performance and even industrial growth in short term. Yet none of these institutional arrangements were sufficient for sustained catch-up in aerospace. Similarly, investments in sustaining the enclave did rarely result in spillovers to the domestic economy given the weak links with domestic industry and education and research organizations. Even if underdeveloped or missing key structural components, innovation systems – or the lack of it – could be identified in all our cases. In the case of China, it was interesting to observe that there may be more than one sectoral innovation system – or rather, that in the history, it was purposefully built with installing certain barriers or blockages to hamper information sharing – but also, effective knowledge exchange between more distant aerospace clusters.[243] These decisions, while probably justified by national security, have continued to create inefficiencies in the performance of the innovation system for a long time.

6.3.5 Innovation system dynamics

The case studies confirmed our expected finding that innovation systems evolve over time, and undergo incremental and radical changes. Radical changes bring about transition periods, of varying length.

The length of these periods varies from country to country. The increased internationalization of production and consumption somewhat synchronizes country experiences. For instance, the end of the Cold War caused a major crisis in the global aerospace industry and all countries that entered the industry at different times and had acquired different levels of capabilities experienced a crisis during the mid-1990s.[244] But in Argentina, Brazil and China major interruptions had already occurred well before the end of

[243] This is not the same as regional differences, e.g. between the Silicon Valley and Route 128 in the US (Saxenian, 1994)
[244] And experience one even more simultaneously during 2008-09, although this remains beyond the scope of this paper.

DOI: 10.14267/phd.2016013

the Cold War. This indicates that country-specific factors matter at least as much as industry-specific ones.

Country-specific factors appear to be similarly important for the length of the period between the beginning of an interruption (indicated by a significant drop in output) and the start of the transition (the creation of a new institutional arrangement in the innovation system).

We distinguished two phases in the successful development of an aerospace industry: an emergent phase and a phase of sustained competitiveness. It is an interesting question whether the end of the emergent phase in aerospace evolution is inevitably associated with an interruption. This seems not to be always the case. In the case of Brazil, the sectoral innovation system had already developed and was functioning well by the early 1980s and the industry had achieved sustained competitiveness, well before the crisis and interruption around 1990. Nevertheless, the transition after 1990 provided an opportunity to decrease the participation of the state in financing innovative activities.

The trajectories of our case study countries show that in all countries public funding was indispensable for the emergence of an aerospace innovation system.[245] In Brazil CTA and ITA were funded by the government and so was Embraer at the time of its establishment. No private capital was channeled into the Chinese innovation system before the 1990s. Similarly, the emergence of the innovation system was funded by public sources in Argentina and Indonesia.

However, while state support is essential during the early years of entry into aerospace, state bureaucracy may become an obstacle as the infant industries become more mature. The sudden withdrawal of the state from a system centered on government (or military) financing – witnessed for instance in Indonesia, Brazil and Argentina – itself represents a system shock, which ultimately requires radical institutional changes – and thus a transition. In this sense, the transition was unavoidable in Brazil.

There are surprisingly many common features in successful innovation system transitions across countries. First, there is a tendency to shift from a military to a civilian innovation system. Second, there is a trend towards increasing participation in international R&D and production networks. This is in accordance with the internationalization of the global industry both in development and production (many of the "organizational innovations" were initiated

[245] In fact, the emergence of an innovation system, which is required to provide the resources needed for competitiveness is what Gerschenkron referred to as the need to substitute the missing institutional prerequisites to growth.

earlier by dominant American and European manufacturers). For the sectors in transition this implies establishing connections with foreign sources of technology and shifting towards more production for export markets.

6.3.6 Interruptions, transitions and the accumulation of technological capabilities

Aerospace producers at medium and higher tiers of the supply chain face immense sunk costs due to the costly machinery and training involved. Firms make these investments if they expect to recover these costs in a long enough production run, or if they expect to be able to expand production cycles by selling related products which require relatively less additional investment. If a production run is interrupted by a temporary decrease in demand, but picks up again, firms may face liquidity problems, but if credit is available to bridge the crisis, they should be able to recover once demand picks up again. However, if the market, following a crisis, demands new products which cannot be supplied with existing capabilities of the company, the company's survival is at risk. It is already experiencing financially troubles, but in order to recover, it needs to invest more in new technologies. This is a typical scenario associated with innovation system transitions.

Evidence from the case studies shows that the speed at which new technological capabilities are accumulated following a transition may be linked to two factors. The first is the absorptive capacity of a firm, which depends on how related prior knowledge is (Cohen and Levinthal, 1990). The second is the financing ability of the firm or the available sources of support within the innovation system. This latter, if linked to a coherent technological development strategy, can compensate for insufficient absorptive capacity. Take the examples of Brazil and China. In Brazil, Embraer's experience in designing commuter and marketing commuter aircraft (the *Bandeirante,* the *Brasilia*) and a jet fighter (the *AMX*) were cosely related to what was required for regional jets (the ERJ-135/145). Yet, it (like most other firms in the global market) lacked financial resources to develop and produce every part and component in-house. The transition involved streamlining the activities, focusing on core competences and establishing collaborative joint ventures to source others. In this way, new private investors saw a growth potential in Embraer required to finance the acquisition of new capabilities related to the core competences. At the same time, using the terminology of Tushman and Anderson (1986), the transition destroyed existing competences of the company. In China, the capabilities of AVIC (and its predecessors) to "design" and "produce" Soviet-style "commuters" and fighter jets were only very distantly related to the

DOI: 10.14267/phd.2016013

aimed commercial regional and larger jets. However, giving the industry strategic priority opened government coffers to finance the acquisition of missing technological capabilities (through license manufacturing MD-80s, producing aircraft parts for western plane makers, co-developing the ARJ-21 with western partners). Apart from the technological relatedness dimension, absorptive capacity at the organisational (firm) level also has a management dimension. The efforts to change practices and routines, or to "un-learning" inefficient solutions should not be underestimated either, as McKendrick's (1992) study on IPTN in Indonesia reveals. In a mammoth-sized AVIC conglomerate the replacement of management practices is especially crucial and explains why the recovery has taken such a long period.

Given the specialization in MRO and product upgrading early on, the absorptive capacity of Singapore Technologies Aerospace was strong. New technologies required to serve a larger MRO market were closely related to what was available earlier. Relatively little organization change or new management practices were required, due to the already existing outward orientation. The transition was a competence-enhancing one.

The negative examples from Argentina and Indonesia similarly fit in this frame. Deficiencies in absorptive capacity of FAMA was excessive in the 1980s, and neither the financially troubled Argentine government or private investors were ready to raise funds. And closing the gap between existing capabilities and what a commercially-oriented innovation system would have required in terms of products, organization of production and marketing capabilities would have been costly. The case was very similar for IPTN / Indonesian Aerospace after the Southeast Asian financial crisis. The large gaps and lack of funds indicate why transitions have not yet occurred.

The previous examples focused on leading firms. Transitions similarly affect the technological capabilities of other firms in the sector. In Brazil, as Embraer was privatized, a number of new firms entered the market, many of them established by previous employees of Embraer. This allowed to preserve certain capabilities at the industry level what the leading firm has lost, but this was only temporary, because in the long run, Embraer increasingly collaborated with foreign component suppliers. Even if some of these suppliers in the last decade established subsidiaries in Brazil, these were more trade posts and did most of the value added activities in their home locations. The case of Singapore is different. The Economic Development Board offered tax breaks and established science parks to invite leading foreign firms to open regional headquarters and production and potentially R&D facilities. As a result, the transition was competence-enhancing and brought new capabilities also in the lower strata of the supply chain.

DOI: 10.14267/phd.2016013

Accumulating technological capabilities involves costs and uncertainties even during periods *between* radical trajectory changes, which originate from the tacit component of knowledge (Lall 1992). The times of radical trajectory changes bring along different kinds of uncertainties and costs that stem from breaking path dependencies and establishing new routines and new channels of learning and collaboration. With regards to external technology sources, the challenge is to identify new partners and create mutual trust. In many of the cases there was a significant element of path dependence in international partnerships across trajectory shifts. This was observable both in Singapore and Brazil, where many of experienced partnerships from the 1980s survived major changes in the 1990s as well. The macro-economic changes in China during the 1990s were deep enough to establish new joint ventures with previously unimaginable western partners, but at the same time the long tradition of collaboration with Russian manufacturers did continue in jet engines and defense systems.

Given the high costs associated with establishing new capabilities for firms, it is good to mention that evidence shows a possibility to prepare for upcoming interruptions and transitions. If actors invest in ‘pre-competitive research’ (research on possible new technologies required to sustain competitiveness), they can ensure a relatively fast transition which lowers the costs of transition. This is especially crucial for latecomer innovation systems that have advanced close to the world frontier. This could already be observed in the cases of Singapore and Brazil in the 2000s. Educational and research institutes play a central part in preparing for upcoming transitions.

6.3.7 Actors that govern the transition period

The competitiveness of the industry during the growth period that follows a transition (or the emergence) depends largely on which actors play a leading role during the transition (or formative) periods. The government is, especially during the emergence phase, indispensable as a key actor. The type of government (military or civilian), its position in the decision-making hierarchy, and the nature of government involvement (did the government impose institutions or did it facilitate the creation of interactions) makes a difference in the structural and functional outcomes of the new innovation system (in the incentive structure, variety creation and selection mechanisms). Countries, where private actors and entrepreneurs were more involved in the creation of institutions, tended to perform more successfully. The

DOI: 10.14267/phd.2016013

comparison of Argentina and Brazil in terms of governance is telling. In both countries the military played a crucial part in the establishment of aerospace research and production activities. But already in the 1970s the success of Brazil owed a lot to entrepreneurial participation and the inclusion of players with a market-oriented mind-set. Similarly, the privatization of Embraer was once again driven by entrepreneurs and was crucial to the elimination of inefficiencies.

If national security considerations are more important for the development of an industry than commercial ones and the transition is completely governed by the military, a failure to establish a sustainable system is almost inevitable. The institutions created during the transition reflected the expectations of one non-market actor, which led to failure in Argentina in the 1950s and in the early decades of the industry's development in China.

6.3.8 Transition institutions

The role of the national innovation system is particularly important in times of transition. Transitions in aerospace can be inspired and supported by similar institutional changes taking place in other sectors of the economy. This was very much the case in China in the 1990s, when the success of reforms in many sectors and regions was a motivating factor for the transition in aerospace as well. The most prominent case is Singapore, where a well-endowed national innovation system provided the basis for a rather smooth system transition. Singapore has constantly increased its investment in education, training and research in areas close to aerospace manufacturing (science, technology and engineering). The globally competitive knowledge base served well the aerospace industry. In addition, active interaction between system components and actors ensured an "early warning" of, and a rapid response to loss of competitiveness. The case of Singapore also shows that an open system of innovation is of paramount importance. Both during the emergence phase and during transition, Singapore attracted expatriate experts and foreign direct investment to fill in the knowledge and capability gaps. This is very much in line with what Galli and Teubal (1997) referred to as "anticipatory institutional changes". Such changes that take place at the higher system level (read, national innovation system) reinforce restructuring at the subsystem level (national aerospace industry) and reduce the effort required for a successful transition.

It is also interesting to consider uncertainty in times of transition. Interruptions and transitions may also take place in innovation systems at the technological frontier, because the same forces of co-evolution may well apply there as well. (The volatile growth of the

DOI: 10.14267/phd.2016013

industry in industrialized countries appears to underscore this assumption.) What is different in the case of latecomers is the degree of uncertainty that actors in latecomer aerospace innovation systems face. The further away they are from the technology frontier, the less the technological uncertainties are and the better they can benefit from benchmarking already established best practices.

Nevertheless, as the very heterogeneous nature of trajectories show, every transition involves a considerable degree of experimentation. These ‘experiments’ are carried out by incumbent actors who are constrained by their existing capabilities and learning abilities, and the usually highly concentrated structure of the industry and the close connection between leading actors and governments make incumbents powerful enough to deter external actors from entering the national sectoral innovation system or limit their actions. This is especially true in cases where the development of the aerospace industry is closely linked to a nationalistic rhetoric. The success of these experimental periods thus depends on the ability of system actors to look beyond the system boundaries.

6.3.9 Factors contributing to the success and failure of transitions

It is a crucial point in interrupted innovation that the emergence of an innovation system does not yet guarantee sustained competitiveness. Only if the system succeeds in surviving a major interruption, will growth restart following a transition, resulting in sustained competitiveness. A successful transition depends primarily on how well key current and potential actors understand the causes of the crisis and the new competitive environment, and how they are able to overcome institutional inertia. In the four country cases, transition did not happen without some form of policy intervention. The question is how to achieve “good governance” of the transition that creates the institutions for long-term growth.

The **successful management of transition** period involves coordinated, strategic intervention. Transition processes are uncertain and changing established routines and laws is costly. However, if an interruption occurs, the cost of “non-transition” also increases rapidly. There are negative externalities in the form of growing unemployment, loss of expertise that can be directly transferred to other industries, deteriorating export performance, and increasing debt burdens in the supplier chain and for development banks. Since the social costs of failure are so high, the government has a legitimate reason to try to initiate systemic change. But firms and entrepreneurs also have an important role given the competitive challenge the industry faces.

DOI: 10.14267/phd.2016013

Both the emergent and the transition phases require coordinated action by the key stakeholders, involving the identification and creation of missing institutional elements. A transition will not occur unless there is sufficient will on the part of the key actors. This may require the formation of explicit or implicit "coalitions" of major actors who can ensure financial and political support for the new system and who can expect major returns from the new system. Firms and entrepreneurs intrinsically have a better understanding of the competitive landscape and can act as 'lobbyists' for system-wide change (cf. Athreye, 2010). Entrepreneurship can also play an important role in identifying the capabilities in the old system that are worth preserving. However, since it is still a catching up system in an emerging economy, underdeveloped infrastructure and missing institutions remain significant impediments to change. For instance the shortage of venture capital was often pointed out in even the best performing country, Brazil.

The nature of entrepreneurship also makes a difference. Short-term rent seeking resulted in less effective concession agreements in Argentina, while aiming for a long-term solution was instrumental for the successful privatization of Embraer. To some extent, competition can also promoted by the government, as the case of China shows. But the lack of competitiveness-driven firms and the absence of an entrepreneurial culture in the Chinese aerospace system may well be the reason why the transition took almost two decades following the interruption in the 1980s.

An **external shock and an interruption during the emergent phase** in a latecomer industry can be fatal. The timing of the first major interruption is one of the important factors explaining the success or failure of transitions. We identified an emergent or formative phase during the initial years of the evolution of the industry and its sectoral innovation system. During this phase the industry has to acquire a minimum level of technological capabilities required to produce aircraft or components utilizing current (or older) technology. Acquiring a threshold level of capabilities is particularly costly in the capital and skilled labor intensive aerospace industry. It involves the creation of some elements of a sectoral innovation system (i.e. firms, aeronautical engineering curricula in higher education, public research organizations, and so forth).

Earlier we criticized the appropriateness of stage theories to describe the evolution of aerospace industry in latecomer countries and argued that the ability to innovate is essential for growth. We have seen that production capacity alone was not enough to sustain the industry in the long term. Although Argentina produced fighters and trainers during the 1970s, and Indonesia produced small transport planes during the late 1980s and mid-1990s,

DOI: 10.14267/phd.2016013

these planes did not meet the quality requirements of the markets and could only be "sold" to their own governments. This was due to the underdeveloped sectoral innovation systems (which lacked a sufficient technological base, private actors, and market incentives in Argentina and a sufficient pool of skilled labor in Indonesia).

Learning by doing is an essential way of accumulating capabilities to innovate. But if learning is inefficient due to the lack of capital and skilled labor, the probability of an interruption occurring before the innovation system has matured sufficiently is high. Such an interruption had devastating effects in Argentina, both at the beginning of the 1950s as well in the 1980s, and in Indonesia in 1997. Brazil, however, survived the interruption in the 1990s because it already had a fairly well-developed sectoral innovation system. Still the system transition lasted four years and involved a fundamental reconfiguration of innovative and productive activities. In China, the innovation system was quite well developed by the 1980s (even if it was not functioning in a competitive way since the incentive was more to achieve a given quantity of output rather than quality) and could therefore survive its interruption.

If the main components of an innovation system are in place, a crisis can be overcome through reconfiguring the institutions, the functions of the various components and their interactions. Had a full-fledged innovation system not yet emerged prior to the crisis, more missing components would need to be supplied in addition to reconfiguring the role of the already existing institutions. Theoretically, considering the arguments on latecomers' advantages and path dependency, the less developed an innovation system is, one might expect that there is less the institutional inertia to overcome. But this reasoning does not hold for aerospace. Countries are more likely to fail if the innovation system is interrupted by a crisis before the phase of emergence has resulted in a full-fledged innovation system. This is illustrated by the examples of Argentina and Indonesia.

The reasons for this relate to the capital intensity of the industry. Competitive aerospace manufacturing depends on sufficient investment capabilities. Following the interruptions in Argentina or in Indonesia, the decline of the industry was due to a lack of investment. The problem here is that the existing level of technological capabilities matters in a crucial way for attracting large amounts of foreign investment. The more developed an innovation system is, the higher its chances to acquire new sources of capital. Latecomers entering the aerospace industry – firms and host governments – need to be ready to invest in the establishment of an innovation system.

DOI: 10.14267/phd.2016013

6.4 Leadership changes

The third research question aimed at understanding, at the level of companies, the drivers of successive catch-up and leadership changes in the regional jet segment. Our framework, based on Perez and Soete (1988), Vertesy and Szirmai (2010) and Lee and Malerba (2013) put particular emphasis on different kinds of windows of opportunity (technological, demand and regulatory), on company innovation strategies devised in response to the emerging windows, and on the preconditions that boosted or hampered potential challengers to effectively implement their strategies. In what follows, we revisit our conclusions presented in section 5.6 to discuss emerging patterns of leadership change and the fate of past leaders, which we find instructive for future contenders and potential investors.

6.4.1 Emerging patterns of leadership change

We found that leadership changes occurred in a relatively short period of time, and were linked to production cycles of families of regional jets. In the case of BAe, the source of leadership was the 146 family (over 1984-1990), in the case of Fokker, it was the F-100/70 (1990-1995), in the case of Bombardier the CRJ family (the CRJ100/200/700/900 models), between 1995 and 2005, with a short interruption in 2000, in the case of Embraer it was the E-Jets (E170/190 models), following 2005. The fact that companies were able to act so fast is due to the capabilities that had already existed in the countries.

Without certain **preconditions**, no challenger could gain leadership in the regional jet market. First and foremost, a precondition was technological and investment capabilities within reach for challenger companies, which is hardly surprising considering the high technological and capital intensity of the sector. None of the newly emerging leader companies were new entrants to the sector by the time they set out to challenge the leadership position of the incumbents; they had already a long experience in aircraft manufacturing. In other words, they paid the cost of entry and passed the steep initial learning curve earlier. Crucially, they possessed absorptive capacity to apply for regional jets technology that already existed in other segments of the aerospace industry. They could also draw upon resources available in the innovation system. That is why government support was crucial to create the preconditions for growth, by training scientists and engineers, performing public research and development and providing favourable business environment and access to external finance and technology in all our cases. We note that alongside the support for the innovation system in a given country hosting the headquarters of a challenger firm, these

DOI: 10.14267/phd.2016013

firms could benefit from the active involvement of other governments that hosted a second-tier component supplier. In this way, all four leaders benefitted from US technology. Furthermore, technological and investment capabilities alone are not sufficient for leadership change, unless these were complemented by a sufficiently deep knowledge of the market, which a company could gain from the sales of related products. In the case of BAe and Fokker, it was the experience with a regional-scale, older generation jet (BAC-111 and F-28), for Bombardier it was the experience as a component supplier (Shorts for Fokker) as well as a turboprop commuter producer, in the case of Embraer, its experience with commuter aircraft operating airlines mattered. This also implied an active engagement in after-sales support and maintenance. The resulting in-depth knowledge of the market was crucial for being able to provide appropriate response to new demand, and thus secure sufficient orders to reach the break-even point.

Company leadership in the regional jet industry has been associated with **leading products**. Leading products are aircraft – or aircraft families with a high degree of similarity with one another but seat ranges or engine performance, i.e. the BAe-146-100/200/300 and the Avro RJ70/85/100 – that constitute the backbone for a company's market leadership, or the largest share of their output in terms of number of deliveries. Over the history of the regional jet industry, leading products were addressing different market segments within the sector. The leadership of BAe and Fokker in the 70-100-seat segment rested upon the fortunes of the BAe-146 and the Fokker F-100, Bombardier owed its success in the 40-50-seat market to the CRJ200, and Embraer once again took the leadership in the larger, 70-120-seat segment with the ERJ-170/190 jets as oil prices rose and smaller regional jets could not compete with turboprop any longer.

Whether a family becomes a leading product, depends on the **timing and duration of windows of opportunities**. The long lead time between the development of the concept of a new aircraft and the entry into serial production brings a fair amount of risk to the enterprise. If an innovator launches the development of a new product having read signals that a combination of window of opportunities have opened, but these windows have been closed by the time the new product enters the market, the cost of failure for the company is enormous. Leadership change therefore depends on the favourable condition and timing of windows of opportunities.

First, typically a technological window of opportunity opens in combination with the promise of a demand window, so that the combination of these two should make it favourable for the innovator to launch the development of a new product. However, in order to turn this

DOI: 10.14267/phd.2016013

new product into a leading product, a demand window, often in combination with a window created by changes in the regulatory environment, should be open at the time when the development process is finalized and the new product is to enter into serial production to boost orders and sales.

Leading products do not necessarily have to be radical clean-sheet designs, but improvements of existing models by re-sizing and re-engining, as in the case of the Fokker 100. However, it appears that the chances of remaining in the market after newly emerging windows of opportunities with these kinds of products may be more difficult than with clean-sheet design, as (at least) two-generation-old vintage platforms easily become uncompetitive. In fact, Fokker’s design and the company did not survive the 1990s challenge, but BAe’s 146 rejuvenated as the Avro jets still generated sales in the 1990s. However, re-engining them as the RJX was not sufficient anymore for the BAe models to survive Embraer’s challenge in the 2000s. Similarly, Bombardier stretched and re-engined its new design and succeeded in extending the production cycle until today, although not anymore as a leading product. This proves that product life cycles matter for competitiveness (Klepper, 1996), and companies that fail to already initiate development of a new product family at the declining phase are at risk of exiting the industry. Slow reaction to windows of opportunities in a competitive environment may be worse than no reaction at all. The lead-time in the sector is long, and there is a real risk of windows of opportunities closing by the time the product receives the necessary certifications for sales. Thus a product’s life-cycle will not be aligned with the windows of opportunities, and low delivery rates not generate sufficient revenue to reach the break-even point and accumulate capital that can be invested in a new clean-sheet design. There is, of course, an element of luck and foresight ability to be able to judge how long windows of opportunities will be available. These two factors, slow response and erroneous judgement contribute to what can be called the “innovators’ trap”, which may be the fate of leaders and followers alike, as once a firm has launched a product development, it is locked in due to the investments and established networks.

The timing of windows of opportunities and the successful launch of potentially leading products have a number of policy implications. Along with the questions of “What did governments do to support challengers?”, or “What did governments do to ensure that current or past leaders are withstanding challengers?”, we also have to ask “When did governments intervene effectively?”. First, preconditions for companies to respond to emerging windows of opportunities depend on the performance of the innovation system, on the availability skilled human resources, basic as well as applied research results from public research

DOI: 10.14267/phd.2016013

organizations, and institutions that facilitate interactions. Second, the speed of response depends on the availability of capital for new entrants to develop and launch a new product, a risky activity where direct or indirect public finance has always played a role and where government loans are (up to a third of the development costs) even compatible with international trade law.[246] Third, governments' regulatory measures can modify windows of opportunities, and instruments such as standard setting, certification or operation requirements, or selection of trading partners have in fact been strategically applied. Fourth, at the time when a new product is ready to enter markets, governments have once again a range of tools at hand to create a trade-friendly business environment. Price is a determinant factor of competitiveness of aircraft, where a weaker currency combined with macroeconomic stability can help, however, if that condition is lacking, governments have found a way for export financing by interest-rate equalization mechanisms or export credits. National prestige aside, it is not leadership but innovation-based competitiveness which may be in the best interest of the public, for what it is equally crucial to ensure that interventions, if exist, are temporary.

The source of windows of opportunities was typically external to the incumbent or challenger companies' activities, however, some institutional factors could be influenced by producers with a large enough size and power. In some special cases, windows of opportunity were opened with the strategic collaboration of key actors in the innovation systems (leading companies, governments, or airlines), such as the creation of favourable tax conditions, an export financing regime, or the preservation and later relaxation of scope clauses. Yet the effectiveness of such "tinkered" opportunities in the longer term depended on the existence of other windows of opportunities (such as sufficient demand).

Windows of opportunity that entailed favourable market conditions or growing demand for regional jets were in principle open for incumbent as well as challenger companies. Incumbents could often not exploit these as much as newcomers because of the sunk costs in their existing (less competitive) products that have not accumulated a break-even delivery volume. This absorbed substantial financial and engineering resources, thus did not have the capacity to respond to challenges. In a few cases where former leaders could liberate some capacity, they could regain their leading positions – as seen in the case of Fokker coming back after it lost leadership with the F-28 to BAe.

[246] See i.e. the 1992 EU – US Agreement on Large Civil Aircraft; the applicability of this agreement to regional jets is debated.

DOI: 10.14267/phd.2016013

The common pattern in firms' strategic response to windows of opportunities over the past three decades entailed the introduction of technologically superior, produced more efficiently in greater production rates. Thus it was an increasing competition to design aircraft with more cost-efficient operational performance, and to be able to offer greater production capacity. Challengers therefore succeeded by ever more focusing on a core competence (lead design, system assembly, sales and after-sales support activities) which allowed efficiency increase and cost reduction. Their main product innovations were new to the regional jet market but not necessarily new to the world: even the organizational innovations (i.e. risk-sharing partnership model) were already introduced in the large civilian aircraft segment earlier. In this sense, the companies can be considered as "strategic followers" (Mathews, 2005) or those scaling down existing technology within an existing architecture (Christensen, 1997).

6.4.2 The fate of past leaders

European aircraft makers of smaller aircraft struggled in a lethal competition in the 1990s, and the collaboration in the framework of Airbus absorbed significant resources and did not succeed in the regional segment. Even if the necessary threshold technological capabilities were available, the financial capacity of firms and individual host governments was limited and targeted mostly the larger civil aircraft segment. Saab, for instance, already had experience in producing a reliable regional turboprop aircraft as well as fighter jets, but has never combined these technologies into commercial jets which would have needed significant investment. Dornier, as a subsidiary of Fairchild, did show its capability by launching the Do-328JET, a 30-seat jet version of its regional turboprop aircraft Do-328, but the performance and efficiency of the aircraft first delivered in 1999 fell short of that of its overseas competitors, and the loss-making company declared insolvency and could not launch a radically new design.[247] The lack of investment capabilities precluded the company from entering the more promising 70-120 with a new design. Evidently, the window of opportunity for 50-seat regional jets in the 1990s opened at the detriment of the turboprop market. Eventually, only the French-Italian ATR consortium managed to survive the shakeouts in the turboprop market that saw the exit of Saab, BAe and Fokker. With hindsight, European companies have made a wrong strategic response by retaining their own programs and not

[247] Nevertheless, the Do-328JET remains the most significant European competitor in the regional jet market, with 110 aircraft delivered.

DOI: 10.14267/phd.2016013

pooling resources as Bombardier managed to do. There are many explanations why no such European consortium could succeed in the regional jet segment (Heerkens et al, 2010). An important reason for producers' inability to collaborate in new projects was their lock-in in parallel programs initiated in the 1980s that proved less cost-efficient than the rest. Product life-cycle in the industry is long, and sunk costs of initial investments can only be recovered after 300-500 aircraft are sold, thus more than two-three companies have no room in a constrained market.

Sunk costs in development and lock-in with a relatively out-of-date design can be just as important a problem for incumbent leaders as for others. In this sense, both BAe and Fokker became victims of their own success. The design of their 100-seat regional jets and the use of international partners to share the burden were efficient and innovative enough to offer a competitive edge in the 1980s. It appeared to be a logical strategy for the companies to invest the limited amount of capital at hand into their competitive advantage serving a promising enough market, rather than embark on an uncertain venture into making a 50-seat jet. To their misfortune, airline economics made the 50-seat jet market more lucrative in the 1990s, and the Bombardier and Embraer aircraft proved to be disruptive innovations in a niche market (Abernathy and Clark, 1985; Christensen, 1997). As a result, their products, the BAe-146 and the F-100, did not generate sufficient revenues to allow investment of own resources in a substantially new development program, and did not have access to additional, significant government funding. On the contrary, both companies were constantly under pressure to economize their operations and were forced to cut workforce in order to be profitable.[248] Fokker was the first to be forced out of business in 1996. The takeover by DASA, a company itself struggling with the EF2000 *Eurofighter* programme and the Dornier operations, did not result in solving Fokker's cash-flow problems. With pessimistic outlook for the Fokker product line, neither the Dutch government nor potential Asian investors could save the company from declaring bankruptcy in 1996.

To mitigate the effect of substantial sunk costs in light of changing technological and demand conditions, a viable option for incumbents is to resize or upgrade existing products. Resizing an existing design in order to better meet market demand has its inherent technical limits. For instance, shrinking the BAe-146 and F-70/100 designs to be competitive against Bombardier and Embraer was not feasible. Upgrading, on the other hand, has proved to be

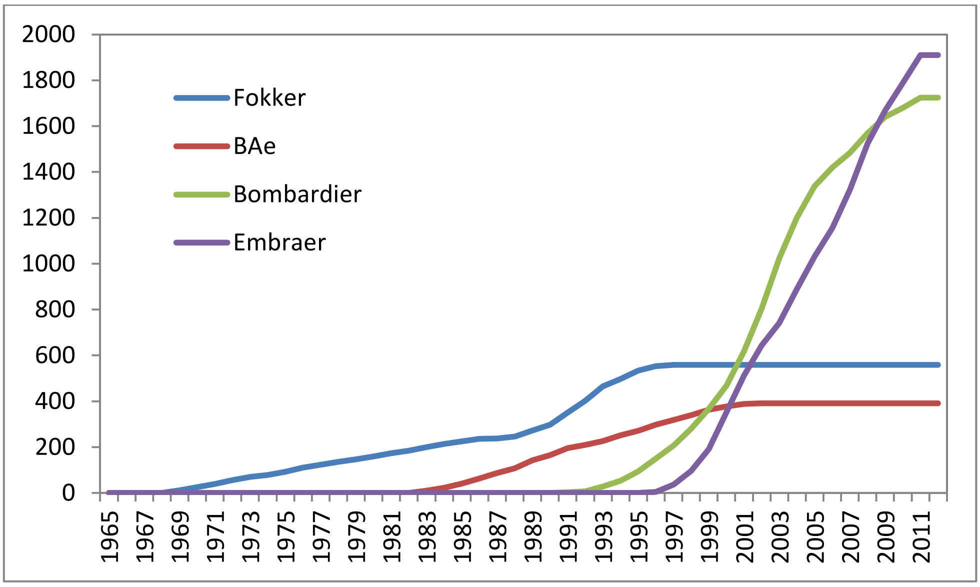
[248] Fokker underwent a rationalization programme in 1994-95 and cut workforce by a third to 8,500 workers and managed to reduce production lead time by half. The Avro operations of British Aerospace took even harsher cuts from 7000 to 1950 jobs in assembly and marketing ("Fokker prepares for new round of cuts" *Flight International*, 22-28 Feb 1995).

DOI: 10.14267/phd.2016013

good solution for British Aerospace, as it managed to conduct an overhaul of the BAe-146 in the Avro RJ programme in 1993. Major changes included adding new Honeywell engines, all digital avionics and a new cabin, which contributed to improved performance and reduced maintenance costs. This way, the life cycles of the three sizes of the BAe-146 (the -100/200/300) were successfully extended, and 170 additional aircraft were sold under the new designation RJ-70/85/100. But as shown earlier, yet another upgrade of these products based on a thirty-year-old design was not marketable any longer after the turn of the millennium, and BAe Systems chose not to raise funds for a clean-sheet design. With another downturn in the industry looming in the wake of 9/11 2001, BAe Systems announced the cancellation of the RJX programme and eventually ended regional jet production two years later. By this strategic move, the company decided to focus its activities on other segments of the aerospace industry (defence, or supplying the large civil aircraft industry) and BAe Systems has remained one of the largest aerospace firms.

It is also interesting to point out that many of the leadership changes overlapped, at least partly, with economic downturns. The first half of the 1990s saw a down-cycle and a consolidation in the global aerospace industry, but the aftermath of 9/11 also brought a shock to the industry. Mathews (2005) and Lee and Mathews (2012) argued that downturns may provide for favourable timing of entry for challenger firms. In fact, we notice that the relatively less costly regional jets offered airlines increased efficiency in contrast with larger aircraft. This clearly aggravated the problems of the incumbents, and British Aerospace and Fokker struggled to reach the break-even point with their regional jets with lower delivery rates.

Figure 6.3 A duopoly change reflected in the cumulative number of regional jets delivered



Source: www.airlinerlist.com; company annual reports

One can also notice another historical trend behind leadership dynamics: the duopoly regime of the 1980s (BAe-Fokker) has, after the painful decade of the 1990s, been replaced by another duopoly regime consisting of Bombardier and Embraer. This also corresponds to a change in the industrial organization from a mostly in-house producing and innovating structure to one relying primarily on global supply chains and risk-sharing collaborations with companies specializing in a narrow segment of the value chain. It is interesting to note that the simultaneous presence of a high number of competitors coincided with relatively low fuel price. This could also have implications for the future competition with new entrants such as Comac's ARJ-21, Mitsubishi's MRJ or the Sukhoi *Superjet* (to list only the aircraft that successfully flew) – should, of course, these companies and their host countries have realized all the necessary preconditions and favourable demand windows open in their favour.

6.4.3 Outlook

Future leadership changes are to be expected in the RJ industry. The capacity of our methodology to predict which company at what time will next assume leadership is limited by the uncertainties as to the nature and timing of new exogenous windows of opportunity. Nevertheless, salient trends can be identified based on known capabilities and revealed strategies. Embraer is likely to maintain its leadership for some years with the overhauled E2

DOI: 10.14267/phd.2016013

jets. Bombardier's fate depends on demand for its C-Series jets in the non-traditional 110-160-seat class.. Unlike past incumbents, Bombardier's product portfolio is diverse enough to help the firm overcome the "incumbent trap". Sustained, low fuel prices may improve the chances for late entrants in the 100-seat class, such as Comac, Mitsubishi or Sukhoi. Even if the models recently introduced fall short of becoming leading products, a modest market presence may provide necessary capabilities for the long-term catch-up and eventual leadership of these firms.

Another question is whether our conclusions on the RJ industry are valid for other capital- and technology-intensive sectors, such as LCA, automobile or shipbuilding, or industries involving complex product systems. While demand conditions may differ across sectors, high capital and technology barriers to entry renders preconditions similarly important. Even in relatively less strategic industries, excluding the role of governments from industry dynamics would be unrealistic.

Finally, one may wonder how specific these conclusions are to the regional jet industry. Other capital and technology-intensive industries, from other segments of the aircraft industry, to other transport equipment sectors, as well as industries involving complex product systems, where accumulating sufficient technological capabilities are necessary for latecomers to be credible challengers, may arguably follow similar paths. Of course, market conditions differ, and competitiveness has a completely different meaning (if any) in the highly geopolitical military aircraft industry than in the automobile or shipbuilding industry. The large commercial aircraft segment would of course show most similarities in leadership dynamics. Such an analysis would nevertheless require a longer historical and narrower geographical scope: at least in the jet age, an initial British leadership in the 1950s was early on replaced by American companies, only to give way to the recently established Boeing-Airbus duopoly. But the nature of preconditions, of windows of opportunity and of strategic response would be very similar.

6.5 Cautionary remarks for companies and governments with aerospace industry ambitions in Central and Eastern Europe

Most of the late entrants discussed in this dissertation were located in emerging economies of Asia and Latin America, but it is important to note that many countries of Central and Eastern Europe (CEE), including Hungary, the Czech Republic, Poland, Romania and Slovakia look back to a century of history in the aircraft industry, and experience similar challenges of

DOI: 10.14267/phd.2016013

crises and the need for a system transition after the collapse of the former Eastern Bloc (Boyko, 2013; Bochniarz et al, 2015).

This dissertation has not focused on helicopters and smaller aircrafts used by general aviation or sports clubs. Typically, the CEE region is active in this segment. While there are potential avenues for upgrading, it should be clear that the regional and large civil aircraft industry is rather saturated at the top. Yet, there are certainly more potential in joining the supply chain and develop niche competencies, considering the "second wave" of internationalization as a global industry context.

At the same time, we note that measuring the spillover effects and conduct a cost-benefit analysis of investing in the aircraft industry remains outside the scope of this study. Neither did we have sufficient and comparable investment data, nor did we think it was possible to account for all costs and gains. We therefore cannot offer any recommendations whether the aircraft industry is a good target for specialization for CEE economies (that is, better than other high-tech activities) – rather, if it is targeted, what should be kept in mind.

First of all, it cannot be overemphasized that aircraft manufacturing is a **business activity**, and all the emerging actors that followed government-led, military-oriented strategies have failed miserably. This is not to say that governments have no role in creating infrastructure, sufficient absorptive capacities, fostering an environment conducive for learning and technological development, access to distant buyers, but the ultimate aim should be delivering products that withstand competition in their own right in the global arena. But finding niche markets, implementing strategies of radical or incremental innovation remains within the scope of companies. From this perspective, policy formation should also be seen as a multi-actor process.

The importance of **foreign investment**, both as a source of new technology and finance should not be underestimated. The case of Singapore showed that significant sustained growth can be achieved without relying on a single "national champion", but with hosting transnational companies. The role for private actors in lower tiers of the industry thus appears to be important for long-term success.

From the finding that interrupted trajectories are ubiquitous in the aerospace industry, we can draw a number of policy lessons **for governments**. In principle, the main role governments can play is to ensure that a sectoral innovation system is well-functioning, to reduce the detrimental effects of crises, and to foster successful transition process in collaboration with business actors in times of radical change. However, it is clear that policies not only have to be tailor-made to the phase (emergence of the industry, transitions or

DOI: 10.14267/phd.2016013

subsequent growth phases), but both the extent to which government involvement may be justified, as well as the length it may be justified vary over time. While a more active role is conducive in times of emergence and transitions, governments should gradually recede during phases of growth.

Creating a well-functioning innovation system entails the **close coordination of policies in multiple domains**: higher education and advanced training; science, technology and innovation policies, industrial and trade policies.

In terms of higher education, a strong knowledge base in natural sciences and engineering is just as important as having strong economics and management training, as the knowledge base of competitive aerospace companies can be very diverse – covering aeronautics, material science, electronics, IT, and also management. The history of Singapore in the 1980s shows that expat experts can complement gaps in the knowledge base in the short term, while the case of Indonesia shows that unless there is are strong local higher education capacities, the industry is at risk of failure. Universities can be ideal sources of creativity and new ideas which are fundamental in an innovation system at any level of industrial development. The public role in supporting world class higher education is unquestionable in both basic and applied sciences, although in the latter; collaboration with industry needs is certainly helps meeting labor market demand and – at least short and mid-term – competitive needs. It should also be kept in mind that educational programmes cannot be adjusted to industry cycles, should therefore aim for longer term which is best at ensuring flexibility of graduates in the future.

As for science, technology and innovation policies, public support to the growth of technology clusters and research facilities is crucial in the emergence phase and in transition phase – that is, strategically attracting business in a given segment. Singapore provides for a good example in providing facilities in industrial parks at favorable conditions significantly reduced entry barriers for foreign subsidiaries and local start-ups, while ensuring that benefits are seen as temporary and all actors aim for gaining competitiveness in the long run. Proximity to the airport, to education, research was similarly an important source of growth for the Sao Jose dos Campos cluster in Brazil. It should of course be noted that the provision of facilities was in both cases complemented with tax breaks and other incentives that not only reduced costs but strengthened the trust of potential investors that the government is committed to long-term development – however, corruption and abuse of public funding is a potential unwanted side-effect which has to be properly addressed, for the sake of avoiding lock-ins with few, inefficient industry actors, such as in the case of Argentina.

DOI: 10.14267/phd.2016013

It is also important to find an “exit strategy” already at phase of introduction of public support. As a new growth trajectory emerges, the need for and scale of public intervention gradually declines. The growth of newly established firms (or resumed growth of old firms that survived a crisis) allows them to increase R&D expenditure. At the same time, policy should closely monitor the evolution of the industry in order to have an early-warning for looming crises and be ready to exploit them as windows of opportunity.

The room for devising trade policies strategically (read, using protectionist measures or activist trade policies) for countries that are members of the WTO, the EU and parties to the OECD agreements related to aircraft trade are significantly narrower than in the case of other latecomers from emerging economies. We have clearly identified strong public support measures in the case of regional jet producers (Brazil as well as Canada); while launch aids and R&D credit have been found in trade disputes to be of equivalent nature. The recent as well as ongoing global trade disputes in civilian aircraft suggests that opposition to export promotion increases, but a general ban on all forms of support to aircraft producers has been and remains out of question. So far the solution was to find a compromise that took into consideration the different country practices of direct and indirect support to local aircraft producers.[249] At the same time, innovators monopolies continue to be a major source of industry asymmetries – a reality for all actors to bear in mind. Furthermore, as trade barriers are declining, so is the importance of the size of domestic market. It was possible for both Brazil and China to effectively protect their commuter planes or fighter planes from foreign competition before the producers went down the learning curve. But since foreign sales were always essential for recovering development costs, the lack of openness may backfire.

Of course, while governments are also among the actors of the system, and are heterogeneous actors – comprising a set of ministries and often military organizations, which operate under uncertainty and have different resources, capacities, information, incentives and short or long-term objectives. Governments, often with little business experience, need also to learn governance practices (Gu and Lundvall 2006). Policy formation itself can be seen as an innovative outcome.

Finally, for companies of Central and Eastern Europe, the main question remains is (and this warrants further investigation), with what activity can they secure the best position in the

[249] For instance, the 1992 EU-US Agreement on Large Civil Aircraft outlined the differences between EU and US support. The agreement made an attempt to balance the EU practice of direct support [to Airbus] in the form of repayable “launch aid” and the indirect, non-repayable R&D support practice of the US.

DOI: 10.14267/phd.2016013

global supply chain – as assemblers of small planes, or as suppliers of knowledge-intensive subsystems, such as avionics, or developers and producers of composite materials. These companies may capitalize from the proximity of related industries, such as automobile, electronics, precision engineering or chemical sector, and from close ties with universities and research institutes. There are many different views concerning the future of aircraft manufacturing and particularly about the future trends of innovations which may cause upcoming radical changes. We have looked at the mechanisms and implications of many of them in the case studies, but it would have been too early to draw meaningful conclusions about future ones in this dissertation.

6.6 Aircraft production, innovation and the changing global balance of power

On the one hand, relatively higher economic growth in emerging economies that create demand for expansion of air transport services, which in turn creates demand for new aircraft, which in turn increases leverage for these countries to attract production and innovation activities, results in a diffusion of production and innovation capacity in emerging economies. On the other hand, greater economic power brings about a greater global political role and often (although not a necessarily implying) an increased demand for stronger military power and the ability to project it further. The result of these trends may lead to the strengthening of the military aircraft industry alongside the civilian, consequences of which go beyond the realms of technological and economic development. However, it is important to acknowledge that changing military power may not only be the source, but also the consequence of aircraft industry development and innovation activities.

Such trends are particularly noteworthy in the case of the so-called BRICS countries. Recent events suggesting the readiness of China to embark on a more activist international presence, the introduction of the air defense identification zone on the East China Sea, the building of new air bases, and the apparent military aircraft development strategies can be seen as important steps evidencing a changing global balance of power. Newly emerging military might can be found in other parts of the world – i.e., Brazil has dispatched Embraer jets for more efficient surveillance of its vast continental territories and its economic interests over the Atlantic. Russian producers are regaining their technological edge thanks to public support and growing export success. As can be seen in reports of the Stockholm International Peace Research Institute (SIPRI), selling military aircraft, equipment and weapons have

DOI: 10.14267/phd.2016013

always included a special strategic bond between buyers and sellers, and a certain degree of dependence of the latter on formers.

None of the countries are new entrants to the military industry. Given the close links between a large share of military and commercial technologies, they can and have capitalized from developments in the civilian segment. However, the close links can also introduce an element of risk when it comes to the question of how sustainable industrial growth can be in the long run – with strong military actors. We have found that there was a major difference in sustainability outcomes between countries where the air force was the sole or dominant buyer of the industry's products and where the commercial segment was also strong. For instance, although military technology and initial orders were crucial for the emergence of the industry in Brazil and Singapore, both Embraer and Singapore Aircraft Industries owed much to their success to meeting the quality and marketing requirements of commercial buyers. Argentina and Indonesia in many ways have fallen victim to the military influence. The Córdoba factory in Argentina remained under the influence of the military. The military was a dominant buyer of IPTN aircraft in Indonesia. China has been a special case, with an increasing strength in the commercial segment alongside the military industry complex, but clearly, the difficulty in commercial jet aircraft launches is influenced by the military dominance in the industry. Yet, nothing is black and white in this sector: military procurement can not only contribute to the development of dual-use models, but can also help the survival of companies in times of crises. For instance, the Brazilian government's support to the launch of the KC-390 transport jet was timed to be counter-cyclical, in a way to mitigate the effect of the 2008 financial crisis. However, if military development goals are not aligned with technology targets for the commercial industry, or not coordinated with other actors of the innovation system, these support measures are of little use – and could result in a permanent reliance on military orders which destroys competitiveness.

From the perspective of hegemonic cycles, we may be experiencing a long transition period in world politics, and at least the transition period may bring about a multipolar world order, with a declining role of the US. The speed of this political transition is unclear. But considering the persistence of US dominance in the sector, it is surprising to find that the speed of transition in the global aircraft industry in terms of production remains relatively slow. At the same time, the region that is more directly challenged by emerging actor is Europe. As in many other domains, it can only be considered as a global industry actor if the dispersed industry actors are more closely integrated.

DOI: 10.14267/phd.2016013

DOI: 10.14267/phd.2016013

Bibliography

ABDI. (2009). Estudo Prospectivo Aeronáutico *Série Cadernos da Indústria ABDI* (pp. 196). Brasília: Agência Brasileira de Desenvolvimento Industrial (ABDI) and Centro de Gestão e Estudos Estratégicos (CGEE).

Abernathy, W. J., & Clark, K. B. (1985). Innovation: Mapping the winds of creative destruction. *Research Policy, 14*(1), 3-22. doi: 10.1016/0048-7333(85)90021-6

Abernathy, W. J., & Utterback, J. M. (1978). Patterns of Industrial Innovation. *Technology review, 80*(7), 40-47.

Abramovitz, M. (1989). *Thinking about growth : and other essays on economic growth and welfare*. Cambridge: Cambridge University Press.

Aerostrategy. (2009). Aerospace Globalization 2.0: The Next Stage. http://www.fac.org.uk/wp-content/uploads/2013/01/200909-AeroStrategy-Globalization-Commentary.pdf (retreived: 2010 Feb)

Akçomak, İ. S., & ter Weel, B. (2009). Social capital, innovation and growth: Evidence from Europe. *European Economic Review, 53*(5), 544-567. doi: 10.1016/j.euroecorev.2008.10.001

Allen, K. W., Krumel, G., Pollack, J. D., & United States. Air Force. (1995). *China's air force enters the 21st century*. Santa Monica, CA: Rand.

Ames, E., & Rosenberg, N. (1963). Changing Technological Leadership and Industrial Growth. *The Economic Journal, 73*(289), 13-31. doi: 10.2307/2228401

Amir, S. (2007). Nationalist rhetoric and technological development: The Indonesian aircraft industry in the New Order regime. *Technology in Society, 29*(3), 283-293. doi: 10.1016/j.techsoc.2007.04.010

Amsden, A. H. (1989). *Asia's next giant : South Korea and late industrialization*. New York: Oxford University Press.

Amsden, A. H. (2001). *The rise of "the rest" : challenges to the west from late-industrializing economies*. Oxford ; New York: Oxford University Press.

Andersen, P. A. (2008). China's Growing Market for Large Civil Aircraft *Office of Industries Working Paper*. Washington, DC: U.S. International Trade Commission.

Archibugi, D., & Coco, A. (2005). Measuring technological capabilities at the country level: A survey and a menu for choice. *Research Policy, 34*(2), 175-194. doi: 10.1016/j.respol.2004.12.002

Ark, B. v. (1993). International Comparison of Output and Productivity *Monograph series no. 1*. Groningen: Groningen Growth and Development Centre.

Ark, B. v., & Gersbach, H. (1994). Micro Foundations for International Productivity Comparisons *Research Memorandum, GD-11*. Groningen: Groningen Growth and Development Centre.

Arreguez, A. C. (2007). *Fábrica Militar de Aviones. Crónicas y Testimonios*. Cordoba: Ministerio de Ciencia y Tecnología, Provincia de Córdoba.

Arrow, K. J. (1962). The Economic Implications of Learning by Doing. *The Review of Economic Studies, 29*(3), 155-173. doi: 10.2307/2295952

Arthur, W. B. (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *The Economic Journal, 99*(394), 116-131. doi: 10.2307/2234208

Asheim, B. T., & Gertler, M. (2005). Understanding Regional Innovation Systems. In J. Fagerberg, D. C. Mowery & R. R. Nelson (Eds.), *The Oxford handbook of innovation* (pp. 291-317). Oxford: Oxford University Press.

Aw, B.-Y. (1991). Singapore. In D. Papageorgiou, M. Michaely & A. M. Choksi (Eds.), *Liberalizing foreign trade. The Experience of Korea, the Philippines, and Singapore* (pp. 309-428). Oxford, UK; Cambridge, Mass.: B. Blackwell.

Balassa, B. (1965). Trade Liberalisation and “Revealed” Comparative Advantage. *The Manchester School, 33*(2), 99-123. doi: 10.1111/j.1467-9957.1965.tb00050.x

Banji, O.-O. (2006). Systems of Innovation and Underdevelopment: An Institutional Perspective. *Science Technology & Society, 11*(2), 239-269. doi: 10.1177/097172180601100201

Baskaran, A. (2001). Competence building in complex systems in the developing countries: the case of satellite building in India. *Technovation, 21*(2), 109-121. doi: 10.1016/S0166-4972(00)00022-5

Baskaran, A. (2005). From science to commerce: the evolution of space development policy and technology accumulation in India. *Technology in Society, 27*(2), 155-179. doi: 10.1016/j.techsoc.2005.01.003

Beaudry, C. (2001). Entry, Growth and Patenting in Industrial Clusters: A Study of the Aerospace Industry in the UK. *International Journal of the Economics of Business, 8*(3), 405 - 436. doi: 10.1080/13571510110079000

Bell, M. (2006). Time and technological learning in industrialising countries: how long does it take? How fast is it moving (if at all)? *International Journal of Technology Management, 36*(1-3), 25-39. doi: 10.1504/IJTM.2006.009959

Bell, M., & Figueiredo, P. N. (2012). Innovation capability building and learning mechanisms in latecomer firms: recent empirical contributions and implications for research. *Canadian Journal of Development Studies / Revue canadienne d'études du développement, 33*(1), 14-40. doi: 10.1080/02255189.2012.677168

Bell, M., & Pavitt, K. (1993). *Accumulating technological capability*. Paper presented at the Proceedings of the World Bank Annual Conference on Development Economics 1992, Washington, DC.

Bell, M., & Pavitt, K. (1995). The development of technological capabilities. In Irfan-ul-Haque (Ed.), *Trade, technology and international competitiveness* (Vol. 22, pp. 69-101). Washington: The World Bank.

Benkard, C. L. (2000). Learning and Forgetting: The Dynamics of Aircraft Production. *The American Economic Review, 90*(4), 1034-1054. doi: 10.1257/aer.90.4.1034

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy, 37*(3), 407-429. doi: 10.1016/j.respol.2007.12.003

Bochniarz, Z., Hruška, Z., Sieńko-Kułakowska, E. B., Pisarczyk, G., & Zbořil, J. (2015). Transformation of the Aviation Industry in Central and Eastern Europe: Czech Republic and Poland. In S. Eriksson & H.-J. Steenhuis (Eds.), *The Global Commercial Aviation Industry* (pp. 318-343). Abingdon, New York: Routledge.

Boeing. (2008). Backgrounder: Boeing in China. Beijing: The Boeing Company.

Boyko, I. (2013). Russian aircraft industry: Between forging ahead and falling behind. *International Journal of Technology and Globalisation, 7*(1-2), 60-79. doi: 10.1504/IJTG.2013.052031

Brander, J. A. (1981). Intra-industry trade in identical commodities. *Journal of International Economics, 11*(1), 14. doi: 10.1016/0022-1996(81)90041-6

Brander, J. A., & Spencer, B. J. (1985). Export subsidies and international market share rivalry. *Journal of International Economics, 18*(1-2), 83-100. doi: 10.1016/0022-1996(85)90006-6

Breschi, S., & Malerba, F. (1997). Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries. In C. Edquist (Ed.), *Systems of Innovation: Technologies, Institutions and Organizations.* (pp. 130-156). London and

Washington DC: Pinter.
Broekel, T., & Boschma, R. (2012). Knowledge networks in the Dutch aviation industry: the proximity paradox. *Journal of Economic Geography, 12*(2), 409-433. doi: 10.1093/jeg/lbr010
Bure, G. d. (2006). *Les secrets de l'Aéropostale : les années Bouilloux-Lafont, 1926-1944*. Toulouse: Éditions Privat.
Cabral, A. S. (1987). *Análise do desempenho tecnológico da industria aeronautica brasileira.* (Doctoral Thesis), ITA, Sao Jose dos Campos.
Cameron, D. (2005). JetBlue launches regional jet lines - FT.com, *Financial Times*. Retrieved from http://www.ft.com/cms/s/0/2baec7f2-3abe-11da-b0d3-00000e2511c8.html
Caracostas, P., & Soete, L. (1997). The Building of Cross-Border Institutions in Europe: Towards a European Innovation System? In C. Edquist (Ed.), *Systems of innovation : technologies, institutions and organizations* (First ed. ed., pp. 395-419). London; Washington, D.C.: Pinter.
Carlsson, B., Jacobsson, S., Holmén, M., & Rickne, A. (2002). Innovation systems: analytical and methodological issues. *Research Policy, 31*(2), 233-245. doi: 10.1016/S0048-7333(01)00138-X
Carlsson, B., & Stankiewicz, R. (1995). On the nature, function and composition of technological systems. In B. Carlsson (Ed.), *Technological Systems and Economic Performance: The Case of Factory Automation* (pp. 21-56). Dordrecht: Kluwer Academic Publishers.
Cassiolato, J. E., Bernardes, R., & Lastres, H. (2002). Transfer of Technology for Successful Integration into the Global Economy: A case study of Embraer in Brazil (pp. 64). New York and Geneva: UNCTAD and UNDP.
Chaminade, C., & Vang, J. (2008). Globalisation of knowledge production and regional innovation policy: Supporting specialized hubs in the Bangalore software industry. *Research Policy, 37*(10), 1684-1696. doi: 10.1016/j.respol.2008.08.014
Chandy, R. K., & Tellis, G. J. (1998). Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize. *Journal of Marketing Research (JMR), 35*(4). doi: 10.2307/3152166
Chandy, R. K., & Tellis, G. J. (2000). The Incumbent’s Curse? Incumbency, Size, and Radical Product Innovation. *Journal of Marketing, 64*(3), 1-17. doi: 10.1509/jmkg.64.3.1.18033
Chang, H.-J. (1994). *The political economy of industrial policy*. New York: St. Martin's Press.
Chang, H.-J. (2003). Kicking Away the Ladder: Infant Industry Promotion in Historical Perspective 1. *Oxford Development Studies, 31*(1), 21 - 32. doi: 10.1080/1360081032000047168
Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*: Harvard Business Review Press.
Cimoli, M., Dosi, G., & Stiglitz, J. E. (2009). *Industrial policy and development : the political economy of capabilities accumulation*. Oxford ; Toronto: Oxford University Press.
Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly, 35*(1), 128-152. doi: 10.2307/2393553
Cooke, P. (1996). The new wave of regional innovation networks: Analysis, characteristics and strategy. *Small Business Economics, 8*(2), 159-171. doi: 10.1007/bf00394424
Cooke, P. (2008). Regional innovation systems: origin of the species. *International Journal of Technological Learning, Innovation and Development, 1*(3), 393 - 409. doi:

10.1504/IJTLID.2008.01998
Cooke, P., & Ehret, O. (2009). Proximity and Procurement: A Study of Agglomeration in the Welsh Aerospace Industry. *European Planning Studies, 17*(4), 549-567. doi: 10.1080/09654310802682115
Craypo, C., & Wilkinson, F. (2011). The Low Road to Competitive Failure: Immigrant Labour and Emigrant Jobs in the US. In J. Michie (Ed.), *The Handbook of Globalisation, 2nd edition* (pp. 356-379). Cheltenham, UK: Edward Elgar.
Dahlman, C. J., Ross-Larson, B., & Westphal, L. E. (1987). Managing technological development: Lessons from the newly industrializing countries. *World Development, 15*(6), 759-775. doi: 10.1016/0305-750X(87)90058-1
Davies, A. (1997). The Life Cycle of a Complex Product System. *International Journal of Innovation Management, 01*(03), 229-256. doi: doi:10.1142/S1363919697000139
della Paolera, G., & Taylor, A. M. (2003). *A new economic history of Argentina*. Cambridge; New York: Cambridge University Press.
Deloitte. (2014). *2014 Global Aerospace & Defense Industry Outlook* Retrieved from http://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-ad-2014-global-ad-industry-outlook.pdf
Dodgson, M., Mathews, J., Kastelle, T., & Hu, M.-C. (2008). The evolving nature of Taiwan's national innovation system: The case of biotechnology innovation networks. *Research Policy, 37*(3), 430-445. doi: 10.1016/j.respol.2007.12.005
Doh, J. (2003). The Bombardier-Embraer Dispute and its Implications for Western Hemisphere Integration *Policy Papers on the Americas* (Vol. XIV). Washington, DC: Center for Strategic and International Studies (CSIS).
Dolata, U. (2009). Technological innovations and sectoral change: Transformative capacity, adaptability, patterns of change: An analytical framework. *Research Policy, 38*(6), 1066-1076. doi: 10.1016/j.respol.2009.03.006
Doloreux, D., & Parto, S. (2005). Regional innovation systems: Current discourse and unresolved issues. *Technology in Society, 27*(2), 133-153. doi: 10.1016/j.techsoc.2005.01.002
Dosi, G. (1982). Technological paradigms and technological trajectories : A suggested interpretation of the determinants and directions of technical change. *Research Policy, 11*(3), 147-162. doi: 10.1016/0048-7333(82)90016-6
Dosi, G., Freeman, C., Nelson, R. R., Silverberg, G., & Soete, L. (1988). *Technical change and economic theory*. London ; New York: Pinter Publishers.
Dosi, G., Hobday, M., Marengo, L., & Prencipe, A. (2003). The Economics of System Integration. Towards an evolutionary interpretation. In A. Prencipe, A. Davies & M. Hobday (Eds.), *The Business of System Integration* (pp. 95-113). Oxford: Oxford University Press.
Dutrénit, G. (2004). Building Technological Capabilities in Latecomer Firms: A Review Essay. *Science, Technology & Society, 9*(2), 209-241. doi: 10.1177/097172180400900202
Dutrénit, G. (2007). The transition from building-up innovative technological capabilities to leadership by latecomer firms. *Asian Journal of Technology Innovation, 15*(2), 125-149. doi: 10.1080/19761597.2007.9668640
Edquist, C. (1997). *Systems of innovation : technologies, institutions and organizations*. London; Washington, D.C.: Pinter.
Edquist, C., & Hommen, L. (2008). *Small country innovation systems : globalization, change and policy in Asia and Europe*. Cheltenham, UK: Edward Elgar.
Eliasson, G. K. (2010). *Advanced public procurement as industrial policy : The Aircraft Industry as a Technical University*. New York; Dordrecht; Heidelberg; London: Springer.
Embraer. (2001). *Embraer Market Forecast, 2001* Retrieved from http://ri.embraer.com.br/

Embraer. (2005). *Airline Market Outlook* Retrieved from ri.embraer.com.br
Engel, J. A. (2000). "We are not concerned who the buyer is": Engine sales and Anglo-American security at the dawn of the jet age. *History and Technology, 17*(1), 43 - 67.
Erickson, R. A. (1974). The Regional Impact of Growth Firms: The Case of Boeing, 1963-1968. *Land Economics, 50*(2), 127-136.
Eriksson, S. (1995). *Global shift in the aircraft industry: a study of airframe manufacturing with special reference to the Asian NIEs.* (Series B, No. 86 PhD Thesis), University of Gothenburg, Gothenburg. (Series B, No. 86)
Eriksson, S. (2003). Indonesia's aircraft industry: technology and management impediments. *International Journal of Technology Transfer and Commercialisation, 2*(2), 207-226. doi: 10.1504/ijttc.2003.003167
Eriksson, S. (2011). Globalisation and changes of aircraft manufacturing production/supply-chains – the case of China. *International Journal of Logistics Economics and Globalisation, 3*(1), 70-83. doi: 10.1504/IJLEG.2011.041426
Esposito, E. (2004). Strategic alliances and internationalisation in the aircraft manufacturing industry. *Technological Forecasting and Social Change, 71*(5), 443-468. doi: 10.1016/s0040-1625(03)00002-7
Esposito, E., & Raffa, L. (2007). Global reorganisation in a high-technology industry: the aircraft industry. *International Journal of Globalisation and Small Business, 2*(2), 166-184. doi: 10.1504/IJGSB.2007.015480
Fagerberg, J. (2000). Technological progress, structural change and productivity growth: a comparative study. *Structural Change and Economic Dynamics, 11*(4), 393-411. doi: 10.1016/S0954-349X(00)00025-4
Fagerberg, J., & Godinho, M. M. (2005). Innovation and Catching-Up. In J. Fagerberg, D. C. Mowery & R. R. Nelson (Eds.), *The Oxford handbook of innovation* (pp. 514-542). Oxford: Oxford University Press.
Fagerberg, J., Mowery, D. C., & Nelson, R. R. (2005). *The Oxford handbook of innovation*. Oxford ; New York: Oxford University Press.
Fagerberg, J., & Srholec, M. (2008). National innovation systems, capabilities and economic development. *Research Policy, 37*(9), 1417-1435. doi: 10.1016/j.respol.2008.06.003
Fagerberg, J., & Verspagen, B. (2002). Technology-gaps, innovation-diffusion and transformation: an evolutionary interpretation. *Research Policy, 31*(8-9), 1291-1304. doi: 10.1016/s0048-7333(02)00064-1
Figueiredo, P., Silveira, G., & Sbragia, R. (2008). Risk Sharing Partnerships With Suppliers: The Case of EMBRAER. *Journal of Technology Management and Innovation, 3*(1), 27-37. doi: 10.1142/9789812770318_0017
Fleury, A., & Fleury, M. T. L. (2011). *Brazilian Multinationals: Competences for Internationalization*. Cambridge, UK: Cambridge University Press.
Fogel, R. W. (1964). *Railroads and American economic growth: essays in econometric history*. Baltimore: Johns Hopkins Press.
Frankenstein, J., & Gill, B. (1996). Current and Future Challenges Facing Chinese Defence Industries. *The China Quarterly*(146), 394-427. doi: 10.1017/s0305741000045082
Freeman, C. (1987). *Technology, policy, and economic performance : lessons from Japan*. London ; New York: Pinter Publishers.
Freeman, C. (1995). The 'National System of Innovation' in historical perspective. *Cambridge Journal of Economics, 19*(1), 5-24.
Freeman, C., & Perez, C. (1988). Structural crises of adjustment: business cycles and investment behaviour. In G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical change and economic theory* (pp. 38-66). London, New York: Pinter.
Freeman, C., & Soete, L. (1997). *The economics of industrial innovation* (3rd ed.).

Cambridge, Mass.: MIT Press.
Freeman, C., & Soete, L. (2009). Developing science, technology and innovation indicators: What we can learn from the past. *Research Policy, 38*(4), 583-589. doi: 10.1016/j.respol.2009.01.018
Frenken, K. (2000). A complexity approach to innovation networks. The case of the aircraft industry (1909–1997). *Research Policy, 29*(2), 257-272. doi: 10.1016/S0048-7333(99)00064-5
Frenken, K., & Leydesdorff, L. (2000). Scaling trajectories in civil aircraft (1913-1997). *Research Policy, 29*(3), 331-348. doi: 10.1016/S0048-7333(99)00037-2
Frenken, K., Saviotti, P. P., & Trommetter, M. (1999). Variety and niche creation in aircraft, helicopters, motorcycles and microcomputers. *Research Policy, 28*(5), 469-488. doi: 10.1016/S0048-7333(99)00008-6
Frischtak, C. R. (1992). Learning, Technical Progress and Competitiveness in The Commuter Aircraft Industry: An Analysis of Embraer. In World Bank Industry and Energy Department (Ed.), *Industry Series Paper*. Washington, D.C.: The World Bank.
Frischtak, C. R. (1994). Learning and technical progress in the commuter aircraft industry: an analysis of Embraer's experience. *Research Policy, 23*(5), 601-612. doi: 10.1016/0048-7333(94)01009-9
Galli, R., & Teubal, M. (1997). Systems of innovation : technologies, institutions and organizations. In C. Edquist (Ed.), *Systems of innovation : technologies, institutions and organizations* (pp. 345-364). London: Pinter.
Geels, F. W., & Kemp, R. (2006). Transitions, Transformation, and Reproduction: Dynamics in Socio-Technical Systems. In M. D. McKelvey & M. Holmén (Eds.), *Flexibility and stability in the innovating economy* (pp. 227-256). Oxford ; New York: Oxford University Press.
Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society, 29*(4), 441-455. doi: 10.1016/j.techsoc.2007.08.009
Gereffi, G., Humphrey, J., Kaplinsky, R., & Sturgeon*, T. J. (2001). Introduction: Globalisation, Value Chains and Development. *IDS Bulletin, 32*(3), 1-8. doi: 10.1111/j.1759-5436.2001.mp32003001.x
Gerschenkron, A. (1962). *Economic backwardness in historical perspective : a book of essays*: Harvard University Press.
Goldstein, A. (2002a). EMBRAER: From national Champion to global player. *Cepal Review*(77), pp. 97-115.
Goldstein, A. (2002b). The political economy of high-tech industries in developing countries: aerospace in Brazil, Indonesia and South Africa. *Cambridge Journal of Economics, 26*(4), 521. doi: 10.1093/cje/26.4.521
Goldstein, A. (2006). The Political Economy of Industrial Policy in China: The Case of Aircraft Manufacturing. *Journal of Chinese Economic and Business Studies, 4*(3), 259 - 273. doi: 10.1080/14765280600991628
Goldstein, A. E., & McGuire, S. M. (2004). The Political Economy of Strategic Trade Policy and the Brazil-Canada Export Subsidies Saga. *World Economy, 27*(4), 541-566. doi: 10.1111/j.0378-5920.2004.00613.x
Golich, V. L. (1992). From Competition to Collaboration: The Challenge of Commercial-Class Aircraft Manufacturing. *International Organization, 46*(4), 899-934. doi: 10.2307/2706878
Gu, S., & Lundvall, B.-Å. (2006). Policy learning in the transformation of the Chinese innovation systems. In B.-Å. Lundvall, P. Intarakumnerd & J. Vang (Eds.), *Asia's innovation systems in transition* (pp. 293-312). Cheltenham, UK ; Northampton, MA:

Edward Elgar.
Hagedoorn, J., & Cloodt, M. (2003). Measuring innovative performance: is there an advantage in using multiple indicators? *Research Policy, 32*(8), 1365-1379.
Hanusch, H., & Pyka, A. (2007). A roadmap to comprehensive neo-Schumpeterian economics. In H. Hanusch & A. Pyka (Eds.), *Elgar Companion to Neo-Schumpeterian Economics* (pp. 1160-1170). Cheltenham, UK; Northampton, MA, USA: Edward Elgar.
Hayward, K. (1994). *The world aerospace industry : collaboration and competition*. London: Duckworth & RUSI.
Heerkens, H., de Bruijn, E. J., & Steenhuis, H.-J. (2009). Common factors in the withdrawal of European aircraft manufacturers from the regional aircraft market. *Technology Analysis & Strategic Management, 22*(1), 65-80. doi: 10.1080/09537320903438104
Heerkens, H., & Ulijn, J. (1999). Fokker, a Clash of Culture? *Journal of Enterprising Culture, 07*(03), 269-298. doi: 10.1142/S0218495899000169
Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change, 74*(4), 413-432. doi: 10.1016/j.techfore.2006.03.002
Henderson, R. M., & Clark, K. B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly, 35*(1), 9-30. doi: 10.2307/2393549
Higham, R. (1968). Quantity vs. Quality: The Impact of Changing Demand on the British Aircraft Industry, 1900-1960. *The Business History Review, 42*(4), 443-466.
Hill, C. W. L., & Rothaermel, F. T. (2003). The performance of incumbent firms in the face of radical technological innovation. *Academy of Management Review, 28*(2), 257-274. doi: 10.5465/AMR.2003.9416161
Hill, H. (1990). Indonesia's Industrial Transformation Part I. *Bulletin of Indonesian Economic Studies, 26*(2), 79 - 120. doi: 10.1080/00074919012331335805
Hanusch, H., & Pyka, A. (2007). A roadmap to comprehensive neo-Schumpeterian economics. In H. Hanusch & A. Pyka (Eds.), *Elgar Companion to Neo-Schumpeterian Economics* (pp. 1160-1170). Cheltenham, UK; Northampton, MA, USA: Edward Elgar.
Hill, H., & Institute of Southeast Asian Studies. (1997). *Indonesia's industrial transformation*. Singapore: Institute of Southeast Asian Studies.
Hill, H., & Pang Eng, F. (1988). The State and Industrial Restructuring: A Comparison of the Aerospace Industry in Indonesia and Singapore. *ASEAN Economic Bulletin, 5*(2), 152-168. doi: 10.1355/ae5-2d
Hira, A., & Oliveira, L. G. d. (2007). Take off and Crash: Lessons from the Diverging Fates of the Brazilian and Argentine Aircraft Industries. *Competition & Change, 11*(4), 329-347. doi: 10.1179/102452906X239501
Hobday, M. (1995). East Asian latecomer firms: Learning the technology of electronics. *World Development, 23*(7), 1171-1193. doi: 10.1016/0305-750X(95)00035-B
Hobday, M. (2003). Innovation in Asian Industrialization: A Gerschenkronian Perspective (Vol. 31, pp. 293 - 314): Routledge.
Hobday, M. (2003). Innovation in Asian Industrialization: A Gerschenkronian Perspective. *Oxford Development Studies, 31*(3), 293 - 314. doi: 10.1080/1360081032000111715
Hobday, M., Davies, A., & Prencipe, A. (2005). Systems integration: a core capability of the modern corporation. *Industrial and Corporate Change, 14*(6), 1109-1143. doi: 10.1093/icc/dth080
Jacobsson, S., & Johnson, A. (2000). The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy, 28*(9), 625-640. doi: 10.1016/S0301-4215(00)00041-0

Katz, J. (2000). Structural Change and Labor Productivity Growth in Latin American Manufacturing Industries 1970–96. *World Development, 28*(9), 1583-1596. doi: 10.1016/S0305-750X(00)00050-4

Kechidi, M. (2013). From 'aircraft manufacturer' to 'architect-integrator': Airbus's industrial organisation model. *International Journal of Technology and Globalisation, 7*(1-2), 8-22. doi: 10.1504/IJTG.2013.052028

Kim, L. (1980). Stages of development of industrial technology in a developing country: A model. *Research Policy, 9*(3), 254-277. doi: 10.1016/0048-7333(80)90003-7

Kim, L. (1997). *Imitation to innovation : the dynamics of Korea's technological learning*. Boston: Harvard Business School Press.

Kim, L. (1998). Crisis Construction and Organizational Learning: Capability Building in Catching-up at Hyundai Motor. *Organization Science, 9*(4), 506-521. doi: 10.1287/orsc.9.4.506

Kim, L., & Nelson, R. R. (2000). *Technology, learning and innovation : experiences of newly industrializing economies*. Cambridge, U.K. New York: Cambridge University Press.

Kimura, S. (2006). Co-evolution of Firm Strategies and Institutional Setting in Firm-based Late Industrialization – The Case of the Japanese Commercial Aircraft Industry. *Evolutionary and Institutional Economics Review, 3*(1), 109-135. doi: 10.14441/eier.3.109

Kimura, S. (2007). *The challenges of late industrialization : the global economy and the Japanese commercial aircraft industry*. New York: Palgrave Macmillan.

King, D. R., & Nowack, M. L. (2003). The impact of government policy on technology transfer: an aircraft industry case study. *Journal of Engineering and Technology Management, 20*(4), 303-318. doi: 10.1016/j.jengtecman.2003.08.007

Klepper, S. (1996). Entry, Exit, Growth, and Innovation over the Product Life Cycle. *The American Economic Review, 86*(3), 562-583. doi: 10.2307/2118212

Klepper, S. (1997). Industry Life Cycles. *Industrial and Corporate Change, 6*(1), 145-182. doi: 10.1093/icc/6.1.145

KPMG. (2004). China aircraft component market. In Kpmg *Advisory* (pp. 15). Hong Kong: KPMG.

Lall, S. (1982). *Developing countries as exporters of technology : a first look at the Indian experience*. London: Macmillan.

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20*(2), 165-186. doi: 10.1016/0305-750X(92)90097-F

Lall, S. (2001). Competitiveness Indices and Developing Countries: An Economic Evaluation of the Global Competitiveness Report. *World Development, 29*(9), 1501-1525. doi: 10.1016/S0305-750X(01)00051-1

Lall, S. (2004). Reinventing Industrial Strategy: The Role of Government Policy in Building Industrial Competitiveness *G-24 Discussion Paper Series*. Geneva: UNCTAD.

Landes, D. S. (1969). *The unbound Prometheus: technological change and industrial development in Western Europe from 1750 to the present*. London: Cambridge U.P.

Lawrence, P. K. (2001). *Aerospace Strategic Trade: How the U.S. subsidizes the large commercial aircraft industry*. Aldershot, Burlington, Singapore, Sidney: Ashgate.

Lee, K., & Lim, C. (2001). Technological regimes, catching-up and leapfrogging: findings from the Korean industries. *Research Policy, 30*(3), 459-483. doi: 10.1016/S0048-7333(00)00088-3

Lee. K. & Malerba, F. (2013). Toward a theory of catch-up cycles: windows of opportunity in the evolution of sectoral systems. Paper presented at the *2013 Globelics International Conference*, 2013 September, Ankara, Turkey.

Lee, K., Mani, S., & Mu, Q. (2012). Explaining Divergent Stories of Catch-up in the

Telecommunication Equipment Industry in Brazil, China, India and Korea *Economic Development as a Learning Process Variation Across Sectoral Systems* (pp. 21-71). Cheltenham, UK: Edward Elgar.
Lee, K., & Mathews, J. A. (2012). South Korea and Taiwan. In Innovative Firms in Emerging Market Countries. In E. Amann & J. Cantwell (Eds.), *Innovative Firms in Emerging Market Countries* (pp. 223-248). Oxford, New York: Oxford University Press.
Lee, S.-Y. (1973). Some Basic Problems of Industrialization in Singapore. *The Journal of Developing Areas, 7*(2), 185-216.
Lee, T.-L., & von Tunzelmann, N. (2005). A dynamic analytic approach to national innovation systems: The IC industry in Taiwan. *Research Policy, 34*(4), 425-440. doi: 10.1016/j.respol.2005.01.009
Ligterink, J. E. (2001). *Corporate Financial Risk Management.* (PhD PhD Thesis), University of Amsterdam, Amsterdam. Retrieved from http://dare.uva.nl/record/1/189609 (uvapub:17687)
Lin, J., & Chang, H.-J. (2009). Should Industrial Policy in Developing Countries Conform to Comparative Advantage or Defy it? A Debate Between Justin Lin and Ha-Joon Chang. *Development Policy Review, 27*(5), 483-502. doi: 10.1111/j.1467-7679.2009.00456.x
List, F. (1841). *Das Nationale System der Politischen Ökonomie (The National System of Political Economy)* (S. S. Lloyd, Trans. 1885 ed.). Stuttgart/Tübingen.
Liu, X., & White, S. (2001). Comparing innovation systems: a framework and application to China's transitional context. *Research Policy, 30*(7), 1091-1114. doi: 10.1016/S0048-7333(00)00132-3
Loftin, L. K. (1985). *Quest for performance : the evolution of modern aircraft*. Washington, D.C.: Scientific and Technical Information Branch For sale by the Supt. of Docs., U.S. G.P.O.
Lukasiewicz, J. (1986). Canada's Encounter with High-Speed Aeronautics. *Technology and Culture, 27*(2), 223-261. doi: 10.2307/3105144
Lundvall, B.-A. (1992). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter.
Lundvall, B.-Å. (2007). National Innovation Systems--Analytical Concept and Development Tool. *Industry & Innovation, 14*(1), 95-119. doi: 10.1080/13662710601130863
Lundvall, B.-Å., Intarakumnerd, P., & Vang-Lauridsen, J. (2006). *Asia's innovation systems in transition*. Cheltenham, UK ; Northampton, MA: Edward Elgar.
Lundvall, B.-A., Johnson, B., Andersen, E. S., & Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy, 31*(2), 213-231. doi: 10.1016/S0048-7333(01)00137-8
Lundvall, B.-A., Vang, J., KJ, J., & Chaminade, C. (2009). *Bridging Innovation System Research and Development Studies: challenges and research opportunities*. Paper presented at the 7th Globelics Conference, Dakar, Senegal.
Macauley, M. K., & Alexander, J. K. (2008). *UNITED STATES CIVIL SPACE POLICY. SUMMARY OF A WORKSHOP*.
MacDonald, L. (2012). *The Bombardier story : planes, trains, and snowmobiles* (2nd ed.). Toronto: J. Wiley & Sons Canada.
MacPherson, A., & Pritchard, D. (2003). The international decentralisation of US commercial aircraft production: implications for US employment and trade. *Futures, 35*(3), 221-238. doi: 10.1016/S0016-3287(02)00055-1
Maculan, A.-M. (2013). Embraer and the growth of the Brazilian aircraft industry. *International Journal of Technology and Globalisation, 7*(1), 41-59. doi: 10.1504/IJTG.2013.052030
Maddison, A. (1998). Measuring the Performance of a Communist Command Economy: An

assessment of the CIA estimates for the U.S.S.R. *Review of Income & Wealth, 44*(3), 307-323. doi: 10.1111/j.1475-4991.1998.tb00284.x

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy, 31*(2), 247-264. doi: 10.1016/S0048-7333(01)00139-1

Malerba, F. (2004). Sectoral systems of innovation: basic concepts. In F. Malerba (Ed.), *Sectoral Systems of Innovation: Concepts, Issues and Analysis of six Major Sectors in Europe*. Cambridge: Cambridge University Press.

Malerba, F., & Mani, S. (2009). *Sectoral systems of innovation and production in developing countries : actors, structure and evolution*. Cheltenham, UK ; Northampton, MA: Edward Elgar.

Malerba, F., & Orsenigo, L. (1996). The dynamics and evolution of industries. *Industrial and Corporate Change, 5*(1), 51-87. doi: 10.1093/icc/5.1.51

Malmberg, A., & Maskell, P. (2002). The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering. *Environment and Planning A, 34*(3), 429-449. doi: 10.1068/a3457

Mani, S. (2013). Evolution of the sectoral system of innovation of India's aeronautical industry. *International Journal of Technology and Globalisation, 7*(1/2), 92 - 117. doi: 10.1504/IJTG.2013.052033

Mani, S., & Romijn, H. (2004). *Innovation, learning, and technological dynamism of developing countries*. Tokyo ; New York: United Nations University Press.

Marques, R. A. (2004). Evolution of the civil aircraft manufacturing innovation system: A case study in Brasil. In S. Mani & H. Romijn (Eds.), *Innovation, Learning and Technological Dynamism of Developing Countries* (pp. 77-106). Tokyo ; New York: United Nations University Press.

Marques, R. A., & Oliveira, L. G. d. (2009). Sectoral system of innovation in Brazil: reflections about the accumulation of technological capabilities in the aeronautic sector. In F. Malerba & S. Mani (Eds.), *Sectoral Systems of Innovation and Production in Developing Countries. Actors, Structure and Evolution* (pp. 156-203). Cheltenham; Northampton, MA: Edward Elgar.

Martin, S. (1999). Trade and Competition: An Industrial Economist's Perspective. *The World Economy, 22*(6), 895-907. doi: doi:10.1111/1467-9701.00237

Martínez-Romero, J. (2013). Towards an aerospace system of production in Mexico? *International Journal of Technology and Globalisation, 7*(1-2), 141-158. doi: 10.1504/IJTG.2013.052034

Maskell, P., & Malmberg, A. (1999). Localised Learning and Industrial Competitiveness. *Cambridge Journal of Economics, 23*(2), 167-185. doi: 10.1093/cje/23.2.167

Mathews, J. A. (2002). Competitive Advantages of the Latecomer Firm: A Resource-Based Account of Industrial Catch-Up Strategies. *Asia Pacific Journal of Management, 19*(4), 467-488. doi: 10.1023/A:1020586223665

Mathews, J. A. (2005). Strategy and the Crystal Cycle. *California Management Review, 47*(2), 6-32. doi: 10.2307/41166293

Mathews, J. A. (2006). Catch-up strategies and the latecomer effect in industrial development. *New Political Economy, 11*(3), 313 - 335. doi: 10.1080/13563460600840142

Matthews, R., & Zhang, N. (2010). Singapore's Aerospace Development 'Model'. In NTU (Ed.), *RSIS Commentaries*. Singapore: Nanyang Technological University.

Mazzucato, Mariana. 2013. *The entrepreneurial state: Debunking public vs. private sector myths*. London, New York: Anthem

McGuire, S. (2007). The United States, Japan and the aerospace industry: from capture to competitor? *The Pacific Review, 20*(3), 329 - 350. doi: 10.1080/09512740701461439

McKelvey, M. D., & Holmén, M. (2006a). *Flexibility and stability in the innovating economy*. Oxford ; New York: Oxford University Press.
McKelvey, M. D., & Holmén, M. (2006b). Introduction. In M. D. McKelvey & M. Holmén (Eds.), *Flexibility and stability in the innovating economy* (pp. xviii, 297 p.). Oxford ; New York: Oxford University Press.
McKendrick, D. (1992). Obstacles to "catch-up': the case of the Indonesian aircraft industry. *Bulletin of Indonesian Economic Studies, 28*(1), 39-66. doi: 10.1080/00074919212331336124
Medeiros, E. S., & Project Air Force (U.S.). (2005). *A new direction for China's defense industry*. Santa Monica, CA: Rand.
Milenky, E. S. (1980). Arms Production and National Security in Argentina. *Journal of Interamerican Studies and World Affairs, 22*(3), 267-288.
Montoro, G. C. F., & Migon, M. N. (2009). *Cadeia produtiva aeronáutica brasileira : oportunidades e desafios*. Rio de Janeiro: BNDES.
Mowery, D. C. (1987). *Alliance politics and economics : multinational joint ventures in commercial aircraft*. Cambridge, Mass.: Ballinger Pub. Co.
Mowery, D. C., & Nelson, R. R. (1999). *Sources of industrial leadership : studies of seven industries*. Cambridge, UK ; New York: Cambridge University Press.
Mowery, D. C., & Rosenberg, N. (1989). *Technology and the pursuit of economic growth*. Cambridge [England] ; New York: Cambridge University Press.
Moxon, R. W. (1987). International Competition in High Technology: The Brazilian Aircraft Industry. *International Marketing Review, 4*(2), 7-20. doi: 10.1108/eb008326
Mu, Q., & Lee, K. (2005). Knowledge diffusion, market segmentation and technological catch-up: The case of the telecommunication industry in China. *Research Policy, 34*(6), 759-783. doi: 10.1016/j.respol.2005.02.007
Mursjid, S. (1998). The Funding of PT DSTP, a High-Technology Project: Lofty goals, defined task. In H. Hill & K. W. Thee (Eds.), *Indonesia's technological challenge* (pp. xxv, 414 p.). Singapore Canberra, Australia: Institute of Southeast Asian Studies; Research School of Pacific and Asian Studies, Australian National University.
Nelson, R. R. (1993). *National Systems of Innovation: A comparative Analysis*. Oxford: Oxford University Press.
Nelson, R. R. (1994). The Co-evolution of Technology, Industrial Structure, and Supporting Institutions. *Industrial and Corporate Change, 3*(1), 47-63. doi: 10.1093/icc/3.1.47
Nelson, R. R. (1995). Co–evolution of Industry Structure, Technology and Supporting Institutions, and the Making of Comparative Advantage. *International Journal of the Economics of Business, 2*(2), 171-184. doi: 10.1080/758519306
Nelson, R. R. (1995). Recent Evolutionary Theorizing About Economic Change. *Journal of Economic Literature, 33*(1), 48-90.
Nelson, R. R., & Pack, H. (1999). The Asian Miracle and Modern Growth Theory. *The Economic Journal, 109*(457), 416-436. doi: 10.1111/1468-0297.00455
Nelson, R. R., & Rosenberg, N. (1993). Technical Innovation and National Systems. In R. R. Nelson (Ed.), *National Systems of Innovation: A comparative Analysis.* (pp. 3-21). Oxford: Oxford University Press.
Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Cambridge, Mass.: Belknap Press of Harvard University Press.
Niosi, J. (2013). Catching up in aeronautics: Introduction to the special issue. *International Journal of Technology and Globalisation, 7*(1-2), 1-7.
Niosi, J., Godin, B., & Manseau, A. (2000). *Canada's national system of innovation*. Montreal ; Ithaca: McGill-Queen's University Press.
Niosi, J., & Zhao, J. Y. (2013). China's catching up in aerospace. *International Journal of*

Technology and Globalisation, 7(1-2), 80-91. doi: 10.1504/IJTG.2013.052032
Niosi, J., & Zhegu, M. (2005). Aerospace Clusters: Local or Global Knowledge Spillovers? *Industry & Innovation, 12*(1), 5 - 29. doi: 10.1080/1366271042000339049
Niosi, J., & Zhegu, M. (2008). *Innovation System Lifecycle in the Aircraft Industry*. Paper presented at the 25th Celebration Conference 2008 on Entrepreneurship and Innovation, CBS, Copenhagen, Denmark. http://www2.druid.dk/conferences/viewpaper.php?id=2885&cf=29
Niosi, J., & Zhegu, M. (2010). Anchor tenants and regional innovation systems: the aircraft industry. *International Journal of Technolgy Management*, *50*(3/4), 263-284. doi: 10.1504/IJTM.2010.032676
Nolan, P., & Zhang, J. (2002). The Challenge of Globalization for Large Chinese Firms. *World Development*, *30*(12), 2089-2107. doi: 10.1016/s0305-750x(02)00148-1
North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge: Cambridge University Press.
Pack, H., & Westphal, L. E. (1986). Industrial strategy and technological change: Theory versus reality. *Journal of Development Economics, 22*(1), 87-128. doi: 10.1016/0304-3878(86)90053-2
Pang Eng, F., & Hill, H. (1992). Government Policy, Industrial Development and the Aircraft Industry in Indonesia and Singapore. In G. van Liemt (Ed.), *Industry on the Move : Causes and Consequences of International Relocation in the Manufacturing Industry* (pp. 235-257). Geneva: ILO.
Patel, P., & Pavitt, K. (1994). National innovation systems: why they are important and how they might be measured and compared. *Economics of Innovation and New Technology, 3*(1), 77-95. doi: 10.1080/10438599400000004
Patel, P., & Pavitt, K. (1994). Uneven (and Divergent) Technological Accumulation among Advanced Countries: Evidence and a Framework of Explanation. *Industrial and Corporate Change, 3*(3), 759-787. doi: 10.1093/icc/3.3.759
Pavcnik, N. (2002). Trade Disputes in the Commercial Aircraft Industry. *World Economy, 25*(5), 733--751. doi: 10.1111/1467-9701.00459
Perez, C., & Soete, L. (1988). Catching up in technology: entry barriers and windows of opportunity. In G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical change and economic theory* (pp. 458-479). London, New York: Pinter.
Polanyi, M. (1967). *The tacit dimension*. London: Routledge & K. Paul.
Poole, E., & Bernard, J.-T. (1992). Defence Innovation Stock and Total Factor Productivity. *The Canadian Journal of Economics / Revue canadienne d'Economique, 25*(2), 438-452. doi: 10.2307/135873
Prencipe, A. (2013). Aircraft and the Third Industrial Revolution. In G. Dosi & L. Galambos (Eds.), *The Third Industrial Revolution in Global Business* (pp. 168-199). Cambridge: Cambridge University Press.
Ramamurti, R. (1987). *State-owned enterprises in high technology industries : studies in India and Brazil*. New York: Praeger.
Reinert, E. S. (2009). Emulation versus Comparative Advantage: Competing and Complementary Principles in the History of Economic Policy. In G. D. M. Cimoli & J. E. Stiglitz (Eds.), *Industrial Policy and Development. The Political Economy of Capabilities Accumulation* (pp. 79-106). Oxford: Oxford University Press.
Romanelli, E., & Tushman, M. L. (1994). Organizational Transformation as Punctuated Equilibrium: An Empirical Test. *The Academy of Management Journal, 37*(5), 1141-1166. doi: 10.2307/256669
Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *The Journal of Political Economy, 94*(5), 1002-1037. doi: 10.1086/261420

DOI: 10.14267/phd.2016013

Rosenberg, N. (1982). *Inside the black box : technology and economics*. Cambridge; New York: Cambridge University Press.
Rosenkopf, L., & Tushman, M. L. (1998). The Coevolution of Community Networks and Technology: Lessons from the Flight Simulation Industry. *Industrial and Corporate Change, 7*(2), 311-346. doi: 10.1093/icc/7.2.311
Ruttan, V. W. (2006). *Is war necessary for economic growth? : military procurement and technology development*. Oxford ; New York: Oxford University Press.
Sarathy, R. (1985). High-Technology Exports from Newly Industrialized Countries: The Brazilian Commuter Aircraft Industry. *California Management Review, 27*(2), 60-84. doi: 10.2307/41165130
Scheetz, T. (1992). The Evolution of Public Sector Expenditures: Changing Political Priorities in Argentina, Chile, Paraguay and Peru. *Journal of Peace Research, 29*(2), 175-190. doi: 10.1177/0022343392029002005
Scheetz, T. (2002). *The Argentine Defense Industry, its Past and Current State: An Evaluation*. Paper presented at the Conference on Defense Offsets and Economic Development, Cape Town, South Africa. http://www.ecaar.org/Articles/SA%20Papers/Scheetz.pdf
Schumpeter, J. A. (1934). *The theory of economic development : an inquiry into profits, capital, credit, interest, and the business cycle*. Cambridge: Harvard University Press.
Schumpeter, J. A. (1942). *Capitalism, Socialism, and Democracy* (Third edition, 1950 ed.). New York: Harper & Row.
Sehra, A. K., & Whitlow Jr, W. (2004). Propulsion and power for 21st century aviation. *Progress in Aerospace Sciences, 40*(4-5), 199-235. doi: 10.1016/j.paerosci.2004.06.003
Silva, O. (2002). *A decolagem de um sonho : a história da criação da EMBRAER* (The take-off of a dream the history of the creation of EMBRAER, Trans. 3a edicao ed.). São Paulo, SP: Lemos Editorial.
Simai, M. (1994). *The future of global governance : managing risk and change in the international system*. Washington, D.C: US Institute of Peace Press.
Simai, M. (2001). *The age of global transformations: the human dimension*. Budapest: Akadémiai Kiadó.
Skolnikoff, E. B. (1993). *The elusive transformation : science, technology, and the evolution of international politics*. Princeton, N.J.: Princeton University Press.
Soete, L. (2007). From Industrial to Innovation Policy. *Journal of Industry, Competition and Trade, 7*(3), 273-284. doi: 10.1007/s10842-007-0019-5
Soete, L., Verspagen, B., & ter Weel, B. (2010). Systems of innovation. In B. Hall & N. Rosenberg (Eds.), *Handbook of the Economics of Innovation, Volume 2*: Elsevier.
Spencer, B. J., & Brander, J. A. (2008). strategic trade policy. In S. N. Durlauf & L. E. Blume (Eds.), *The New Palgrave Dictionary of Economics*. Basingstoke: Palgrave Macmillan.
Spencer, J. W., Murtha, T. P., & Lenway, S. A. (2005). How governments matter to new industry creation. *Academy of Management Review, 30*(2), 321-337. doi: 10.5465/amr.2005.16387889
Steenhuis, H.-J., Bruijn, E. J. D., & Heerkens, H. (2007). Technology transfer and catch-up; lessons from the commercial aircraft industry. *International Journal of Technology Transfer and Commercialisation, 6*(2/3/4), 250-278. doi: 10.1504/IJTTC.2007.017809
Stuivenwold, E., & Timmer, M. (2003). Manufacturing Performance in Indonesia, South Korea and Taiwan before and after the Crisis. An international Perspective, 1980-2000 *Research Memorandum GD-63*. Groningen: Groningen Growth and Development Centre.
Szalavetz, A. (2013). Régi-új világgazdasági jelenségek a globális értékláncok tükrében. *Külgazdaság, 57*(3-4), 46-64.
Szirmai, A. (2005). *Dynamics of socio-economic development : an introduction*. Cambridge,

DOI: 10.14267/phd.2016013

UK ; New York: Cambridge University Press.
Szirmai, A. (2009). Industrialisation as an engine of growth in developing countries *UNU-MERIT Working Paper Series* (pp. 50). Maastricht: United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology.
Szirmai, A. (2012). Industrialisation as an engine of growth in developing countries, 1950–2005. *Structural Change and Economic Dynamics, 23*(4), 406-420. doi: 10.1016/j.strueco.2011.01.005
Szirmai, A., Ren, R., & Bai, M. (2005). Chinese Manufacturing Performance in Comparative Perspective, 1980-2002 *Discussion Paper No. 920*. New Haven, CT: Yale Economic Growth Center.
Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509-533. doi: 10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z
Texier, F. (2000). *Industrial diversification and innovation : an international study of the aerospace industry*. Cheltenham, UK ; Northampton, MA: Edward Elgar.
Timmer, M. P. (2000). *The dynamics of Asian manufacturing : a comparative perspective in the late twentieth century*. Cheltenham, UK ; Northampton, MA, USA: Edward Elgar.
Tushman, M. L., & Anderson, P. (1986). Technological Discontinuities and Organizational Environments. *Administrative Science Quarterly, 31*(3), 439-465. doi: 10.2307/2392832
U.S. Dept. of Commerce. (2009). Flight Plan 2009: Analysis of the U.S. Aerospace Industry. In O. o. T. a. M. I. T. Administration (Ed.), (pp. 70). Washington, D.C.: U.S. Department of Commerce.
U.S. Dept. of Commerce. (2009). Flight Plan 2009: Analysis of the U.S. Aerospace Industry. In Office of Transportation and Machinery International Trade Administration (Ed.), (pp. 70). Washington, D.C.: U.S. Department of Commerce.
UNIDO. (2005). *Industrial Development Report 2005. Capacity Building for Catching-up: Historical, Empirical and Policy Dimensions*. Vienna: UNIDO.
USITC. (2001). Competitiveness Assessment of the U.S. Large Civil Aircrafts Aerostructures Industry: U.S. International Trade Commission.
Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega, 3*(6), 639-656. doi: 10.1016/0305-0483(75)90068-7
Veblen, T. (1919). *The place of science in modern civilisation and other essays*. New York: B.W. Huebsch.
Vernon, R. (1966). International Investment and International Trade in the Product Cycle. *The Quarterly Journal of Economics, 80*(2), 190-207. doi: 10.2307/1880689
Vertesy, D. (2011). *Interrupted Innovation. Emerging economies in the structure of the global aerospace industry.* (PhD PhD Thesis), Maastricht University, Maastricht. Retrieved from http://arno.unimaas.nl/show.cgi?fid=23802
Vertesy, D. (2013). The lion with wings: Innovation system dynamics in the aerospace industry of Singapore. *International Journal of Technology and Globalisation, 7*(1-2), 118-140. doi: 10.1504/IJTG.2013.052027
Vertesy, D. (2015). The Contours of the Global Commercial Aircraft Manufacturing Industry. In S. Eriksson & H.-J. Steenhuis (Eds.), *The Global Commercial Aviation Industry* (pp. 1-32). London: Routledge.
Vertesy, D., & Szirmai, A. (2010). Brazilian aerospace manufacturing in comparative perspective: A Brazil/USA comparison of output and productivity *UNU-MERIT Working Paper Series*. Maastricht: United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology.
Viegas, J. A. (1989). *Vencendo o azul: história da indústria e tecnologias aeronáuticas no Brasil*. São Paulo: Duas Cidades.

DOI: 10.14267/phd.2016013

Vincenti, W. G. (1979). The Air-Propeller Tests of W. F. Durand and E. P. Lesley: A Case Study in Technological Methodology. *Technology and Culture, 20*(4), 712-751. doi: 10.2307/3103637

Vincenti, W. G. (1984). Technological Knowledge without Science: The Innovation of Flush Riveting in American Airplanes, ca. 1930-ca. 1950. *Technology and Culture, 25*(3), 540-576. doi: 10.2307/3104204

Wade, R. (1990). *Governing the market : economic theory and the role of government in East Asian industrialization*. Princeton, N.J.: Princeton University Press.

Walsh, J. F. (1998). Sales forecasting in cyclical markets. *Business Economics, 33*(3), 35.

Westphal, L. E. (2002). Technology Strategies For Economic Development In A Fast Changing Global Economy. *Economics of Innovation & New Technology, 11*(4/5), 275. doi: 10.1080/10438590200000002

Wong, P. K. (2003). From using to creating technology: the evolution of Singapore's national innovation system and the changing role of public policy. In S. Lall & S. Urata (Eds.), *Competitiveness, FDI and technological activity in East Asia* (pp. 191-238). Cheltenham; Northampton, MA: Edward Elgar.

World Bank. (1993). *The East Asian Miracle*. Washington, D.C.: World Bank.

Yin, R. K. (2012). *Applications of case study research* (3rd ed.). Washington DC: Sage.

Yuan, L., Zhongfeng, S., & Yi, L. (2010). Can strategic flexibility help firms profit from product innovation? *Technovation, 30*(5-6), 300-309. doi: 10.1016/j.technovation.2009.07.007

Yun, H. A. (2004). Innovative Milieu and Cooperation Networks: State Initiatives and Partnership for Restructuring in Singapore. In P. Cooke, M. Heidenreich & H.-J. Braczyk (Eds.), *Regional innovation systems : the role of governance in a globalized world* (pp. 291-326). London ; New York: Routledge.

Zhegu, M. (2013). Technology policy learning and innovation systems life cycle: The Canadian aircraft industry. *International Journal of Technology and Globalisation, 7*(1-2), 23-40. doi: 10.1504/IJTG.2013.052029

List of related publications by the author

Book chapters in English:

Vertesy, D. (2015). The Contours of the Global Commercial Aircraft Manufacturing Industry. In S. Eriksson & H.-J. Steenhuis (Eds.), *The Global Commercial Aviation Industry* (pp. 1-32). London: Routledge.

Vertesy, D. (2011). The evolution of the Chinese and Argentine aircraft manufacturing industries. In M. Santillán, M. H. & Rubiolo (Eds.), *América Latina y el Este Asiático: Perspectivas desde Córdoba*. Córdoba, Argentina: CIECS-CONICET Universidad Nacional de Córdoba.

Book chapters in Hungarian:

Vértesy D. (2008). "Utazás az innovációs rés mélyére", in: Palánkai *et al* (szerk.) *Három éve az ötven éves EU-ban*, Konferenciakötet, Budapest: BCE.

Peer-reviewed articles in English:

Vertesy, D. (2013). The lion with wings: Innovation system dynamics in the aerospace industry of Singapore. *International Journal of Technology and Globalisation, 7*(1-2), 118-140. doi: 10.1504/IJTG.2013.052027

Vertesy, D., Annoni, P. & Nardo, M. (2013). University Systems: Beyond League Tables. Engines of Growth or Ivory Towers? *Higher Education Evaluation and Development*, 7(1), 21-43. doi: 10.6197/HEED.2013.0701.02

Peer-reviewed articles in Hungarian:

Vértesy D. (2008), "Mi motiválja Közép- és Kelet-Európa vállalatainak K+F kiadásait?" *Társadalom és Gazdaság*, 30(1), pp.115-137. doi: 10.1556/TarsGazd.30.2008.1.7

Vértesy D. (2006), "Fejlődő feljesztés? Fejlesztési- és támogatáspolitika az ENSZ keretében 1945 és 1990 között" *Grotius – A Budapesti Corvinus Egyetem Nemzetközi Tanulmányok Intézetének tudományos folyóirata*.

Other articles:

Vértesy, D. (2011). „Global Insider: The Brazilian Aerospace Industry" *World Politics Review*; 10 Jan 2011, p.3.

Muchie, M., Vértesy, D., Baskaran, A., Na-Allah A. A. (2009). Book Reviews *African Journal of Science, Technology, Innovation & Development*, Vol 1, Nr. 2-3, 2009.

Working papers:

Van Roy, V., Vértesy, D. & Vivarelli, M. (2015). Innovation and Employment in Patenting Firms: Empirical Evidence from Europe, *Institute for the Study of Labor (IZA) Discussion Papers,* No 9147.

Vertesy, D. (2014). Successive leadership changes in the regional jet industry *UNU-MERIT Working Paper Series,* 2014-046.

Vértesy, D. & Szirmai A. (2010). Interrupted Innovation: Innovation System Dynamics in Latecomer Aerospace Industries, *UNU-MERIT Working Paper Series,* 2010-059; újra közölve: *Globelics Working Paper* Nr. 10-02.

DOI: 10.14267/phd.2016013

Vértesy, D. & Szirmai A. (2010). "Brazilian aerospace manufacturing in comparative perspective: A Brazil/USA comparison of output and productivity", *UNU-MERIT Working Paper Series*, 2010-032.

Conference presentations and publications:

Vértesy, D. (2014). Successive Leadership Changes in the Regional Jet Industry presentation paper presented at the conference *Future perspectives on innovation and governance in development*, Maastricht, The Netherlands 26-28 Nov 2014

Saltelli A., Saisana M., and Vértesy D., (2013). Advocacy, Analysis and Quality. The Bermuda triangle of statistics. Presentation at the *What way forward for European and Hungarian Statistics?* conference of the Hungarian Statistical Association, Budapest, 20-21 Nov 2013

Vértesy, D. (2013). Changing leadership in the regional jet industry, Paper presented at the *Conference on Changes in the Industry Leadership and Catch-up Cycles*, Seoul, South Korea 12-13 May 2013.

Vértesy D. (2012). Measuring Innovation, presentation at the 2012 Cyprus Presidency – JRC Conference *Scientific Support to Innovation in the Services Sector*, Nicosia, 13 December 2012.

Vértesy D. (2012). Exploring research performance of countries and knowledge-led growth, *Proceedings of the 10th Globelics 2012 International Conference*, 9-11 November 2012, Hangzhou, China

Vértesy D., Annoni, P., Nardo, M. (2012). "Regional University Systems: Engines of Growth or Ivory Towers?" Paper presented at the *IREG-6 Conference:The Academic Rankings and Advancement of Higher Education*. *Lessons from Asia and Other Regions.* Taipei (Taiwan) 18-20 Apr 2012.

Vértesy, D. (2011), Charting the Changing Landscape of the Aerospace Manufacturing Industry, Paper presented at the *9th Globelics International Conference*, Buenos Aires (Argentina) 15-17 Nov 2011.

Other refereed publications:

Hardeman S., Van Roy V., Vértesy D. and Saisana M. (2013). *An analysis of national research systems (I) A Composite Indicator for Scientific and Technological Research Excellence* EUR 26093. Luxembourg (Luxembourg): Publications Office of the European Union; doi: 10.2788/95887

Hardeman S. and Vértesy D. (2013). *An analysis of national research systems (III): towards a composite indicator measuring research interactions* EUR 26405 EN Luxembourg (Luxembourg): Publications Office of the European Union; doi: 10.2788/50714

Vértesy D. and Van Roy V. (2013). *Update on the Composite Indicators of Structural Change towards a More Knowledge-Intensive Economy* EUR 26409 EN Luxembourg (Luxembourg): Publications Office of the European Union; doi: 10.2788/51665

Vértesy D., Tarantola S. (2012). *Composite Indicators of Research Excellence*. EUR 25488 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. doi: 10.2788/45492

Vértesy D., Albrecht D. & Tarantola S. (2012). *Composite Indicators measuring structural change, to monitor the progress towards a more knowledge-intensive economy in Europe,* Luxembourg: Publications Office of the European Union; doi:10.2788/20444

DOI: 10.14267/phd.2016013

Tarantola, S., Vértesy D. & Albrecht D. (2012). *Composite Indicators measuring the progress in the construction and integration of a European Research Area*, Luxembourg: Publications Office of the European Union; doi: 10.2788/20356

Vertesy, D. (2011). *Interrupted innovation: Emerging economies in the structure of the global aerospace industry*. Phd Dissertation, Maastricht: Universiteit Pers Maastricht