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Interrupted innovation: Innovation system dynamics in latecomer aerospace industries

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Interrupted Innovation:
Innovation System Dynamics in Latecomer Aerospace Industries

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Abstract

In this paper we analyse the role of sectoral innovation systems in the emergence and catch-up of aerospace industries in latecomer economies. We argue that the aerospace sector is characterized by a process of interrupted innovation. Competitive pressures and the cyclical nature of the industry not only require shifts in the direction of innovation and changes in the production system, but also periodical restructuring of the whole sectoral system of innovation.

Aerospace manufacturing requires advanced technological capabilities at the earliest stages of the emergence of the industry. Producers immediately need to comply with high international technology, quality and safety standards. Stage models of gradual technological upgrading in the process of catch up are therefore not appropriate to analyse the evolution of this industry in latecomer economies. The model of interrupted innovation developed in this paper provides an alternative perspective.

In country case studies of Brazil, China, Indonesia and Argentina, we show how changes in the global competitive landscape and major political developments trigger crises in the industry, with which existing systems of innovation are unable to cope. Competitive pressures periodically require the industry to reinvent itself almost from scratch.

We conclude that the emerging economies that have succeeded in catching up in aerospace are those that have established a competitive industrial sector with a sectoral innovation system which is able to adapt flexibly to radically changing circumstances.

Keywords: aerospace manufacturing, sectoral innovation systems, system dynamics, latecomer industrialization, technological capabilities

JEL Codes: L62, O14, O31, O32, O33, O38

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Interrupted Innovation: Innovation System Dynamics in Latecomer Aerospace Industries

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1 Introduction: Aerospace industries and the Model of Interrupted Innovation

This paper analyses the emergence and evolution of the aerospace manufacturing industry in a number of developing countries in the post-war period. We argue that an understanding of success and failure in establishing and sustaining growth in this industry in latecomer countries is not possible without a joint analysis of both the production system and the innovation system. Building on the innovation systems literature, the paper develops a model of interrupted innovation, which focuses on the ability of the actors in the sectoral innovation system to radically shift course when faced with the periodical crises that characterize the aerospace industry. This model has been developed on the basis of four country case studies and serves to structure the presentation of them.

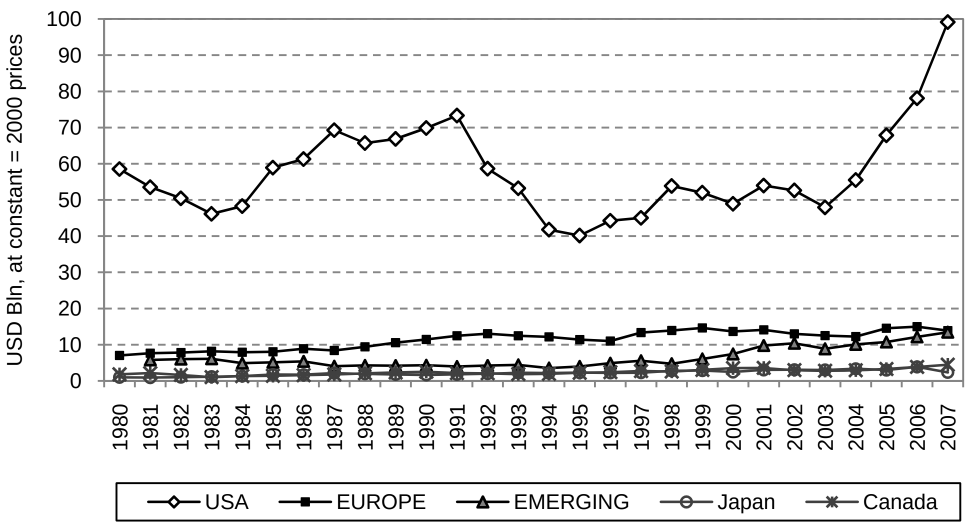
The paper is organised as follows. Section 2 documents the entry of developing countries into the global aerospace industry. Section 3 discusses the literature on latecomer industrialization and the specific characteristics which make the aerospace sector different from other sectors and affect its role in catch up. In Section 4, we construct a conceptual framework of interrupted innovation which allows us to compare various modes of innovation system change; in sections 5, 6, 7 and 8 we discuss four case studies of Brazil, China, Indonesia and Argentina. The Brazilian and Chinese case studies are based on primary field visits to Brazil and China as well as on secondary data and literature. The case studies of Indonesia and Argentina are based on secondary materials. 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. Section 9 concludes.

2 Emerging economies in the global aerospace industry

The global aerospace industry has undergone a number of transformations throughout the second half of the 20th century. The arrival of the jet age in the 1950s, the increasing global flows of people, commodities and services and the gradual liberalization of the air transport market resulted in rapid growth of air traffic around the world, although primarily between the advanced economies. In the last two decades global aircraft manufacturing experienced a period of shakeout and consolidation, with the emergence of global supply chains and with large-scale mergers and acquisitions taking place in Europe and North America (Nolan and Zhang, 2002). Apart from the traditional industrial clusters[2], only a few new ones have emerged.[3]

For decades, the aerospace industry[4] has been dominated by first mover manufacturers from North America, Western Europe and the Soviet Union. Over the second half of the 20th century, a number of newly industrializing countries have attempted to set up production facilities, mainly driven by military considerations (Goldstein 2002). These include Argentina, Brazil, India, Indonesia, Israel, South Korea, South Africa and Turkey as well as P.R. China, Singapore and Taiwan. Following initially mixed results, a few emerging countries, including Brazil and China, have developed their capabilities for aerospace production and have successfully entered the global market. Our data show that they have experienced accelerated growth and catch-up in aerospace industries. Catch-up is understood here as a narrowing of the technological gap resulting in substantial gains in global value added shares of latecomer economies compared to their advanced country competitors.

Figure 1 Value Added in Aerospace Manufacturing (1980-2007)
(Billion USD at constant = 2000 prices)



Notes: Emerging economies include Brazil, Colombia, P.R. China, Hong Kong SAR, India, Indonesia, Malaysia, Mexico, Rep. Korea, South Africa, Taiwan, Turkey and Singapore; Aerospace refers to ISIC Rev.3 class 353; Europe is an aggregate defined by the geographic area.
Sources: Groningen Growth and Development Centre 60-Industry Database (GGDC), OECD STAN, Brazilian Institute of Geography and Statistics (IBGE), UNIDO, Chinese National Bureau of Statistics (CNBS), various yearbooks; industry of origin conversion ratios applied from GGDC.

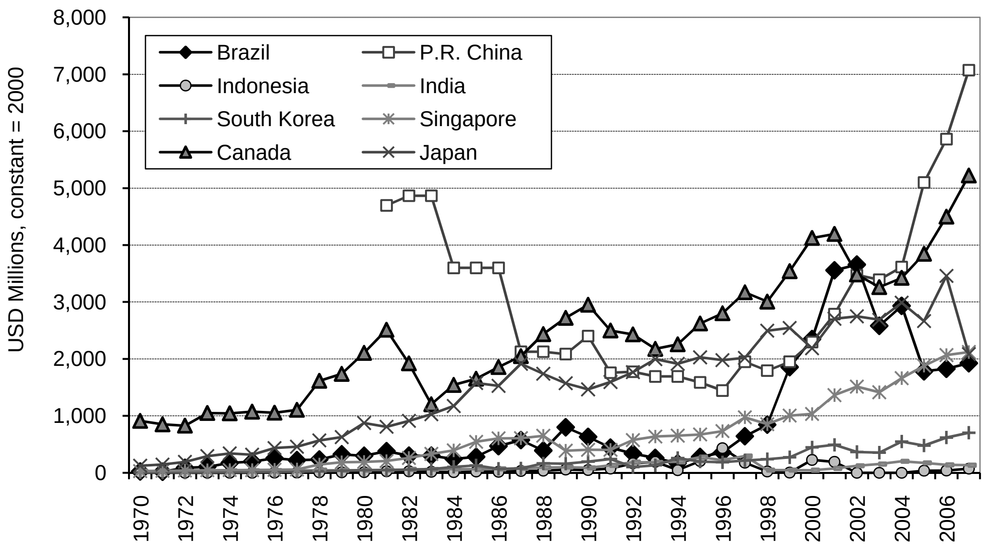
Figure 1 compares the emerging economies with the leaders. Compared to the United States, aerospace manufacturing value added in emerging countries amounted to less than 6 per cent in 1990. It grew rapidly to 20 per cent by 2002, before declining again to

[2] For a study on why spillovers favor clusters in the sector, see Niosi and Zhegu (2005).
[3] A first historical sketch of catch-up in aerospace was presented by Niosi (2009). We came across the paper while finalizing this study.
[4] The aerospace industry is defined as the manufacturing of aircraft, spacecraft, their engines and propulsion systems, parts and components. The focus of this paper is primarily the aircraft which is the bulk of the industry.

14 per cent in 2007. (The decline in relative shares was driven by growth of US output after 2003. In absolute terms developing country value added grew threefold from 1990 to 2007, reaching 13.5 billion USD in 2007).

Figure 2 focuses more on dynamics of latecomers. In terms of sales volume and value added the most successful emerging economies have overtaken incumbent producers such as France and Italy by the year 2000. They are now challenging Canada and Japan. The share of emerging countries in global value added doubled in a decade to nearly 10 per cent by 2000. Global value added shares peaked at 13 per cent and subsequently declined to 10 per cent in 2007. The most successful of the late entrants, Embraer of Brazil is now among the top five commercial aircraft manufacturers in the world. The figures for China need to be regarded with caution. Chinese aerospace conglomerates produce a range of products outside the aerospace classification. If commodity based figures were available similar to what is reported for Brazil, Chinese value added would presumably be lower than that of Brazil at the turn of the millennium. The fact that Brazilian value added has recently been declining, even while Embraer's turnover has been increasing, indicates that the sector is facing a competitive challenge.

Figure 2 Value added in aerospace, selected emerging countries (1970-2007)
(Million USD at constant = 2000 prices)



Sources: GGDC and OECD STAN; IBGE, UNIDO, CNBS, various yearbooks; industry of origin conversion ratios applied from GGDC.

3 Catch Up in Aerospace: A new perspective on the dynamics of sectoral innovation systems

3.1 *Latecomer trajectories and competitiveness*

The Gerschenkronian tradition has emphasized the possibility of accelerated growth and catch up in follower economies due to access to global technology, without having to bear the cost and risks of developing this technology (Gerschenkron, 1962). All examples of accelerated growth in manufacturing in developing countries fit the Gerschenkronian pattern. Some catch up countries have succeeded in entering high-tech industries (e.g. the South East Asian tigers and their entry into electronics). They have benefited from higher value added output ratios associated with the technology-intensive production (Fagerberg, 2000). Aerospace is such a high-tech industry, but as will be shown in this section, it differs from other high-tech sectors.

Historical evidence shows a great variety of trajectories from infant industries to mature, competitive ones. The strategies governments and firms devised and implemented in order to accumulate the capabilities required for growth also varied significantly. Nevertheless, observers of the successful catch-up of latecomers in high-tech industries in Southeast Asia have been keen to find commonalities between the country experiences. While it is fiercely debated whether more general lessons can be drawn from the East Asian experiences (Hobday, 2009), there is a broad consensus how the successful latecomers have reached technologically more advanced stages of production. This has resulted in a number of stage models.

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 (1982) emphasized that industries progressed from *elementary* through *intermediate* to *advanced learning* capabilities. Hobday (1995:1185) 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.

Compared to other industries, aerospace has some very distinctive features. Hardly any other industry experiences such severe demand fluctuations, which are so closely correlated with fluctuations in global economic growth. Aerospace firms need to be prepared for cyclical changes in demand and recurrent crises within the lifetimes of their products.

Aerospace manufacturing is a leader in technology intensity (Smith, 2005) and is also highly capital intensive. New entrants face a 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 support manufacturers, either through launch subsidies, export subsidies, military procurement or market protection. To justify support, governments argue along the lines of national security, prestige and expected spillovers [5] to downstream industries and services [6] and to other sectors of the economy. Finally, aerospace stands at the intersection of different kinds of policy interventions: industrial policies, higher education policies and science and technology and innovation policies.

The aerospace industry presents latecomers with a special challenge because of its technologically complex products. At the core of many stage models of catch-up models there is a tradeoff between cost and quality. A cheaper but less reliable or less advanced 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 any other sector, given that an aircraft or spacecraft is as reliable as its weakest component. Latecomer firms cannot sell their products unless they successfully meet the high standards set by the global industry leaders. Intensive technological learning and local adaptation are needed even in cases where only foreign technologies and designs are applied. The production processes of component suppliers are meticulously screened by the system assembler companies; governments cannot (temporarily) relax standards for new producers without jeopardizing public safety. Consequently none of the stage theories discussed above are applicable to the aerospace industry. To start up series production in aerospace, firms need to possess advanced learning capabilities from the very beginning. They need to have assimilated and adapted a wide range of relevant technologies. Firms or the governments supporting them need to have the resources to make huge launch investments.

Designing a new prototype of an aircraft or a component does not yet ensure that it will be a successful product. Without successful securing orders to support series production, there can be no catch-up; without competitive products, there can be no series production. Competitiveness requires the production of technologically complex products at an early stage in the evolution of the industry. Even if these products are not at the technology frontier, they may be new to the market [7] they are serving. Unless latecomer, state-sponsored producers find enough customers other than their respective governments to become financially sustainable, they will become too big a burden for the public to support. Ultimately, their governments and domestic firms will be forced to purchase high quality aerospace products from competitors.

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[5] Measuring spillovers effects related to the aerospace industry remains 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.

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

[7] Market in the case of this industry includes not only civilian but military as well.

The central question is not what stages a latecomer aerospace industry needs to go through along its development trajectory, but rather,

- how firms can acquire the set of capabilities required to compete in the market segment they aim at, at the time of entry; and
- how it can develop self-sustaining mechanisms to generate the capabilities to continue to compete in a changing and volatile environment?

Firms that succeeded in sustaining their competitive edge over time were innovators who launched new products (even if that meant applying already existing technologies in new combinations), introduced new methods of production or organization of production and sales activities. They could not have done it without a supportive environment – an innovation system – that offered firms access to resources[8] they required to innovate. The emergence of sectoral innovation systems provides the key to catch-up in latecomer aerospace.

In our view, it is sufficient to distinguish only two "phases" in the evolution of latecomer aerospace industries. An emergent phase in which some countries find a niche for their products, and the subsequent drive for sustained competitiveness. 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, there is a transition to sustained competitiveness. But this transition can also fail in which case the industry will languish or disappear altogether. Whether the transition can be made depends on the flexibility of the innovation system.[9] This will be further elaborated in sections 3.2-3.4. Section 4 presents a conceptual framework for the analysis of such transitions, referred to as 'the framework of interrupted innovation'.

3.2 *Emerging industry and innovation system*

The emergence of an industry and its sectoral innovation system in a late industrializing economy is a special phase within its overall evolution. Latecomer firms face disadvantages in terms of having to overcome both technology barriers and market barriers (Hobday, 1995:1172).

What characterizes the initial phase is a gradual overcoming of competitive disadvantages stemming from lack of technological and market capabilities. On the one hand, firms are dislocated or isolated from sources of technology, R&D, and a supply of adequately trained and skilled labor and they lack linkages with advanced country markets that they wish to supply. The firms' primary aims thus focus on acquisition of technology, human capital and access to markets. On the other hand, being a latecomer offers a potential for accelerated growth and catch-up by being able to avoid the risks, uncertainties and costs of innovation at the frontiers of knowledge, by having potential access to already available technology and knowledge (Gerschenkron, 1962). But reaping these opportunities and accumulating the required capabilities is a costly and difficult process (Perez and Soete, 1988).

Choices facing governments and entrepreneurs in this phase are related to finding ways to benefit from technological backwardness and profit from a variety of knowledge

[8] Such as access to a pool of skilled labor force, credits, tax incentives, etc.

[9] Achieving sustainability is not a once and for all achievement. The industry is faced with recurrent challenges which may threaten its future competitiveness unless new adjustments are made.

spillovers. These choices include whether a technology should be acquired from outside or developed locally ("make or buy" dilemma), what market segment(s) to focus operations on, what financing mechanisms to set up and how to educate and train scientists, engineers and managers.

It is important to emphasize the evolutionary nature of this phase. Actors have to cope with a high degree of uncertainty, and have to take risks and prepare for an iterative process. For instance, Hobday (2009) argues with regard to Asian development that what would turn out to be successful was not foreseen or meticulously planned in advance.

Historical evidence varies hugely how long it takes for an industry to go beyond the emerging phase, especially because it is hard to find a distinct dividing line. The length of the emergence phase depends on the one hand how successfully the new products sell (initially profiting from subsidies and government support) and on the other hand on the readiness of competitors and trading partners to accept infant industry protection. Formal international trade disputes may be good indicators of the end of the emergence phase. These will force governments to shift to more subtle forms of industrial support.

By the end of the emergent phase, firms in the industry need to have learnt not only to produce but also to compete by innovating. This learning process takes place within the realm of a sectoral innovation system, which faces challenges such as: (a) bringing together and ensuring a sustainable supply of inputs, including physical capital and human capital, the technological base; (b) organizing learning and search directions for further technology and (c) fostering interactions (d) devising appropriate institutions, given the historical context and conditions of demand and competition. The development of the innovation system will be discussed later in this section.

3.3 *Sustaining competitiveness*

By the end of the emergent phase, the industry is assumed to have developed a leading segment and its main focus will be to sustain competitiveness. In 2000, both Japan, the producer of aircraft parts and components (including those made of composite materials) and Brazil, the assembler of regional jets (mostly from parts made elsewhere) had a value added in aerospace production of around 2.5 billion dollars (see Figure 2). In their own segments, both countries were highly competitive, yet these segments are vertically dependent on one another. Both require a complex, but very different set of technological capabilities which their firms have evidently mastered. It matters less in which specific segment of the industry a country produces, more how successfully it does so. What matters is the degree of competitiveness. A competitive segment of an industry is characterized by competitive prices, ability to meet international quality standards, increasing volume of production and growing global markets shares.

Competitiveness in a technology intensive industry is more than merely having a static competitive edge based on factor endowments such as low wages. In a dynamic perspective, it refers to increasing value added per person while wages rise, diversification into more complex activities and increasing technological and organizational capabilities (Lall and Mortimore, 2005:3).

Given the fact that no aerospace producer has ever achieved market success without some form of government intervention, it is national sectors rather than single firms that compete with each other in various market segments. Thus shifting from the emergent phase to the phase of sustained competitiveness requires the reconfiguration of both firm strategies and the role of the government. It does not necessarily imply a complete withdrawal of government intervention. Rather it implies that protectionist policies and inward looking import substitution policies (that were deemed acceptable on the part of a newly industrializing country) are replaced by more subtle forms of government support. This policy shift is also imposed by competitor firms and countries. As mentioned above, international trade disputes are good indicators of competitiveness in aerospace industries. They provide an indication of a country's success in the eyes of its competitors. The outcomes of these disputes also shape the "standard" of what is an acceptable degree of intervention in the international community.[10]

Sustained competitiveness has to be supported by a well-functioning sectoral innovation system, characterised by dense and multidimensional interactions between actors (including market- as well as non-market interactions, through both formal and informal knowledge channels). If competitiveness is understood in the dynamic sense, the innovation system should be able to respond to (and spur) changes in demand and be able to supply leading firms with an adequate knowledge base to compete successfully on the market.

3.4 *Failing to sustain competitiveness*

It is not inevitable that the emergent phase of an industry is followed by a sustained competitive phase. Governments can distort market signals (e.g. through military procurements) and motivate favoured domestic firms to produce products that cannot compete on foreign markets in the absence of continued support. Firms can fail with their innovation, or more advanced competitors can abuse their market and political power. To sustain competitiveness, firms need constantly to expand their technological capabilities. If the technological gap vis-à-vis leading foreign competitors widens during a given phase, insufficient capabilities limit latecomers' competitiveness. Regaining competitiveness requires additional financial inputs, yet this needs to be recovered from future sales. The continuous lack of market success (either civilian or military) thus potentially leads to unsustainable development.

Had the innovation system functioned properly, it would respond to competitive challenges leading to a narrowing of technology gaps. But structural problems and institutional rigidities may result in an innovation system that is not flexible enough to adapt effectively to changing market conditions. Missing actors or blocked linkages between actors result in a slowdown of the provision of technology, ideas or finance. In such situations radical institutional reform is required to overcome stagnation or falling behind. Lack of competitiveness will potentially escalate to a crisis where financing production and innovation becomes unsustainable. Avoiding these crises and achieving a system-wide response is crucial to decrease excessive dependence on government funding and provide sustained growth for the latecomer aerospace industry.

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[10] For greater details on international trade disputes of aircraft manufacturers, see Pavcnik (2002) or Goldstein and McGuire (2004).

4 A conceptual framework of interrupted innovation

4.1 *Sectoral innovation systems*

The competitiveness of an industrial sector is closely related to the performance of its sectoral innovation system (Mowery and Nelson, 1999; Malerba, 2002). From a dynamic perspective, the competitiveness of a productive sector depends on its firms' ability to accumulate technological capabilities in a changing environment. Firms learn how to respond to demand, how to produce. While doing so, their capabilities co-evolve with the scientific and technological knowledge frontier, with the institutions that regulate access to and appropriation of such knowledge, and with change production and trade regimes. This co-evolution between production system and innovation system is apparent in the interactions between firm and other organizations and institutions[11]. Such processes of co-evolution differ from sector to sector (Malerba, 2002).

In accordance with Malerba's definition of a sectoral production and innovation system (2002), the aerospace industry is characterized by its products, inputs, actors (firms and other organizations), its scientific and technological (S&T) knowledge base and the interactions between the actors and organizations. Innovative and productive activities co-evolve given that actors simultaneously introduce carry out both innovative and productive activities. Malerba proposes that "for analytical purposes one could examine separately a sectoral innovation system, a sectoral production system and a sectoral distribution-market system" (2002: 251). We follow Malerba in distinguishing a separate sectoral innovation system. But since our ultimate goal is to explain sectoral growth and catch-up, will explicitly link developments in a more narrowly defined innovation system to developments in the production system.

A sectoral system of innovation is the source of technological change in an industry. (Innovations may include blueprints of new products, modification to existing blueprints and designs, a new ways of production or organizing industrial activity. They may originate in R&D departments designed explicitly to generate innovations but also derive from non-R&D employees as well as from the users of the industry's products. The information and knowledge exchanges of the innovation system are closely connected to the production activities of the industry. These relationships between firms, organizational and individual actors within an innovation system adhere to a set of rules, considered as the institutions. For innovation systems to function, these rules need to be clearly defined and acted upon. This means that the functioning of the innovation system – or at least its core – requires continuity and stability in the medium term. However, from time to time, components of the system, including actors, their capabilities as well as the institutions defining their relationships need to change radically. The framework we present below sheds more light on these changes.

[11] Institutions are understood in the sense of being "rules of the game" that are "humanly devised constraints that shape human interactions" (North 1990). They are not to be confused with organizations (such as R&D research labs, educational institutes) which have formal purpose and structure.

4.2 *Incremental and Radical Changes in innovation systems*

Analysis of the emergence and dynamics of an industry also implies the analysis of the corresponding emergence and dynamics of the sectoral innovation system. However, the existing literature rarely makes this relationship explicit, leaving the dynamics of innovation systems under-researched. There are especially large gaps in our knowledge concerning innovation systems in developing countries.[12]

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) 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, 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.[13] 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) single out the institutional set-up 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) 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'. The functional dynamics literature discusses a

[12] As Lundvall recently noted: "Notwithstanding the clear links between innovation system research and evolutionary economics, understanding the dynamics of different innovation systems and different evolution paths still remains a major research challenge in innovation system research, particularly when dealing with developing countries." (Lundvall et al, 2009:30-31).

[13] Most relevant studies are 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, or Malerba and Mani 2009,

similar kind of transition, although 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 institution, it is fair to say regardless of the perspective, all strands of literature appear to agree that following a successful transition, the basic functions or structure (or architecture[14]) 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.

The framework outlined below takes a structural approach and focuses on changes in the main building blocks of a system (á la Malerba 2002).

4.3 *The main components of the framework of interrupted innovation*

The *size of an innovation system* is defined by the input of resources into innovation and technological change (investment in R&D, human capital engaged in the development of new products and processes or organizational change as well as marketing or economically applicable knowledge).

We refer to the *performance of the innovation system* as the supply 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 innovative performance 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.[15] Indicators characterizing innovation performance could include the number of new product

[14] 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.

[15] The literature does not provide a clear definition of the performance of an innovation system. Nor does it provide simple ways to measure it.

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 use proxy indicators of productive performance such as the industrial sales performance (including sales on domestic and export markets) and market shares of final products.

When the innovation system is supplied with additional resources, innovation performance will increase. But within the constraints of a given innovation system, long-run performance is constrained by diminishing returns – similar to a production function with diminishing returns to scale.[16] 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.

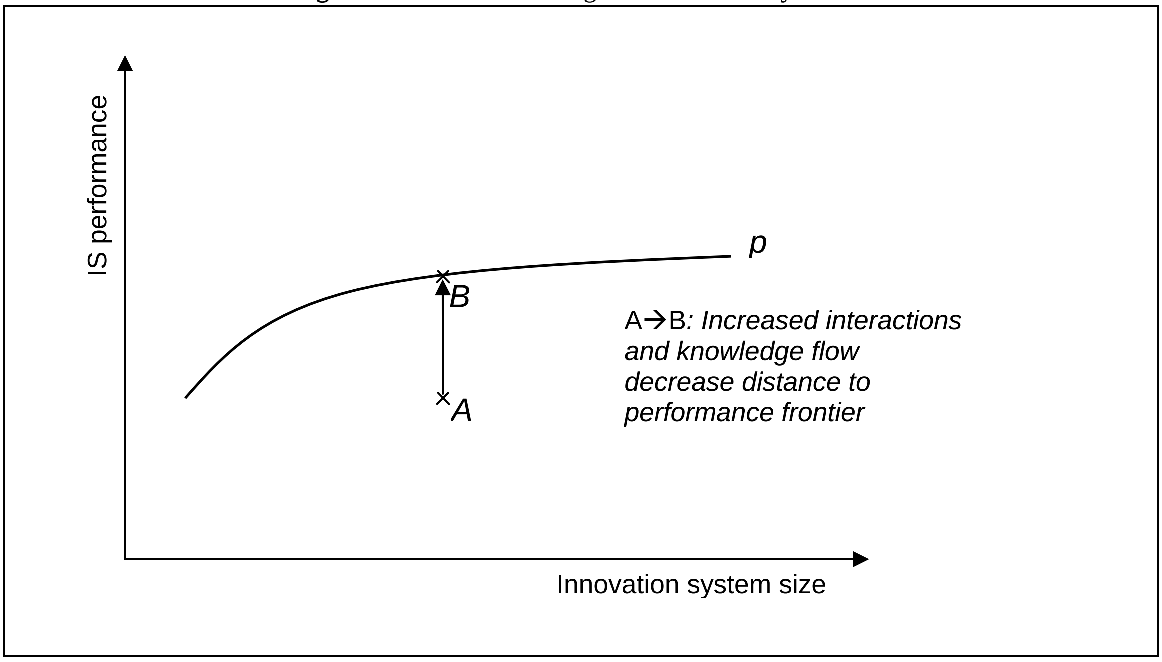
Below, we attempt to visualize the relationship between size and performance of a sectoral innovation system and the effect of institutional change in a set of graphs. These graphs should be seen as metaphors, given that we do not yet have precise operational measures of aggregate innovation system performance.

4.4 *Learning within an innovation system*

Figure 3 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 given the amount of resources invested in the system (horizontal axis).

[16] 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.

Figure 3 Performance in a given innovation system



4.5 *Movement of the innovation system frontier*

The performance frontier can shift as a result of two kinds of change: (A) incremental and (B) radical institutional changes.

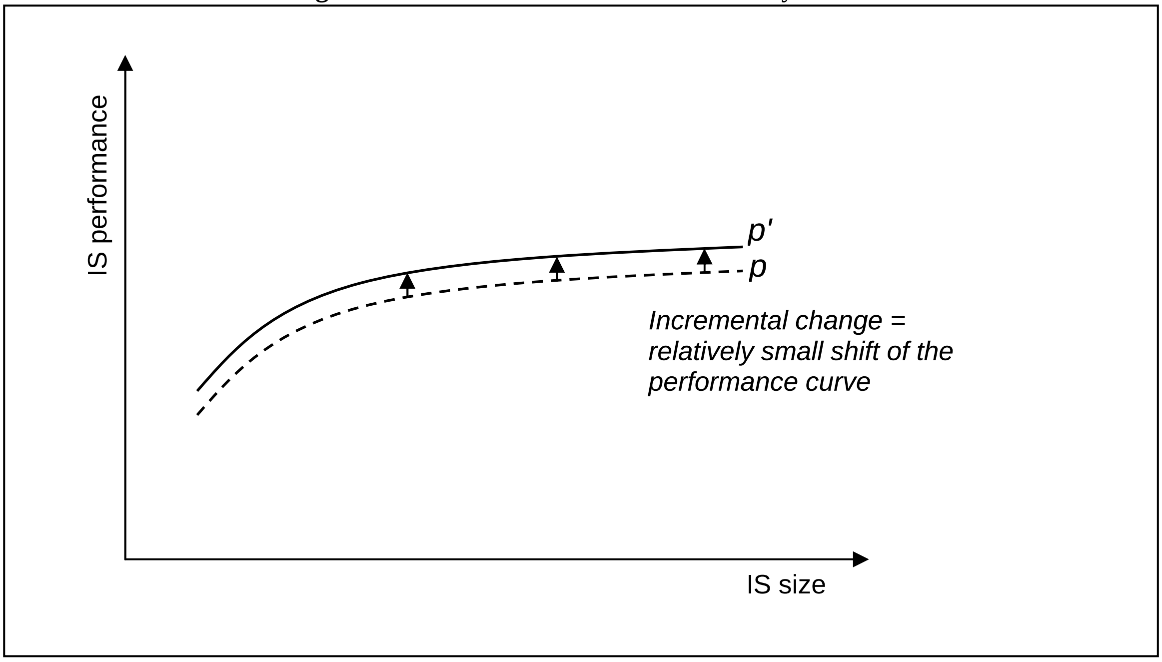
A. Incremental Shifts

The first type of change refers to smaller adjustments to the setup of the innovation system itself that influences the performance. Small, often iterative improvements and changes in the nature and organization of interactions within a system, possibly as a result of institutional learning within the system, but can also happen due to factors that are exogenous to the system which increase performance (e.g. spillovers from other systems). For instance, smaller changes in tax or trade law are institutional changes that might positively affect system performance. Yet they are limited in scope and do not alter the fundamental structure and interactions of the system.

In Figure 4, this is illustrated with a relatively small vertical shift of the performance frontier curve (from *p* to *p'*). The key point is that because of the creative forces in the system, a race to the frontier is a race to a moving finish line. However, the main feature of such incremental changes is that the core resources and key institutions of the sectoral system of innovation remain essentially the same.

Incremental shifts can be distinguished from learning and increased interaction within a given system, as depicted in Figure 3. Incremental change involves a measure of system change and institutional learning; refers to learning to work a given system.

Figure 4 Incremental shift of the innovation system



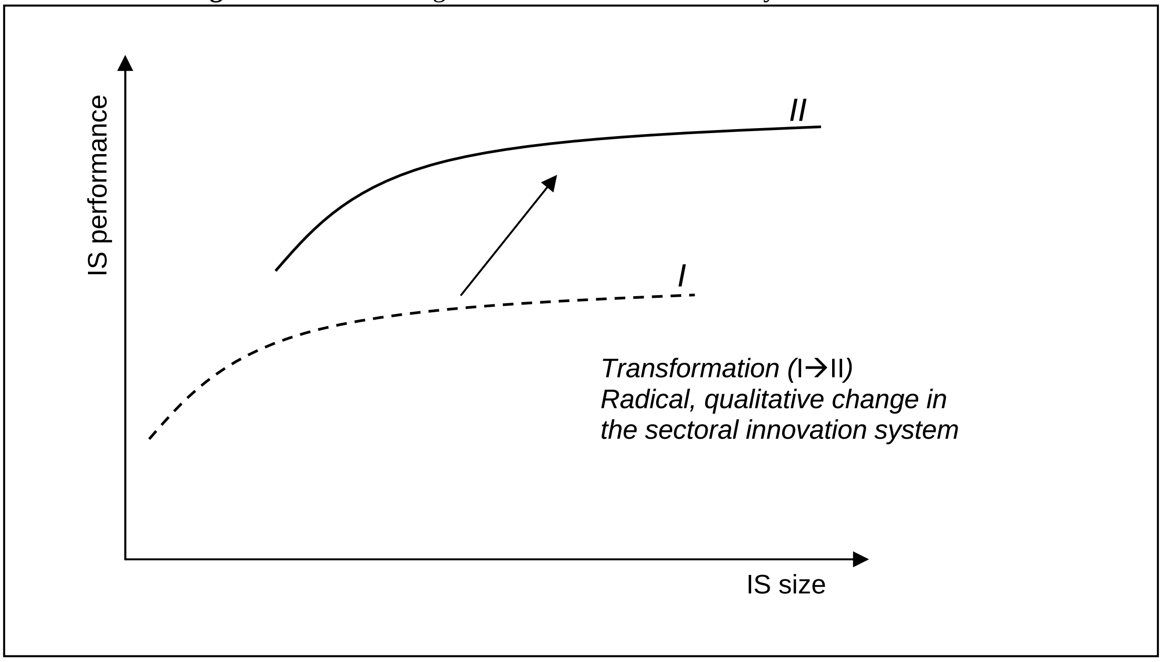
B. Radical shifts

A more radical shift of the system is caused by a more fundamental, qualitative change in its constitution. These changes include the entry of new actors with new capabilities that affect existing relations, a significant change in the technological base of the system, and, crucially, a change of institutions. Figure 5 shows 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 increased 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 of innovation system dynamics this simple model can illustrate. Analysis of industrial development can reveal for instance how regularly these shifts occur, what triggers them or what the direction of changes was.

The aim of any competitive industry is to continue to increase its innovative performance, in other words, to shift the innovation performance curve upward. 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).

Figure 5 Radical Change of the Sectoral Innovation System: Transition



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 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.[17] In a behind-the-frontier latecomer system exogenous causes of interruption are more likely to happen than creative destruction caused by endogenous forces, which presumes that the industry has already reached the global technological frontier.

4.6 *Innovation system trajectories*

Graphs 6, 7 and 8 plot how the size and performance of a sectoral innovation system in a country changes over time as a result of learning and institutional changes. The trajectory of a country is indicative of the way its institutions function and reveals the major constraints to and opportunities for industrial competitiveness, related to the functioning of the innovation system. In this section we disregard incremental shifts and only discuss learning with a system and transition to another system.

Let us consider a latecomer industrializer for an example (Figure 6). 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,

[17] We refer to a radical technological change on the frontier if we assume that the latecomer system is closing the technology gap. But of course, this is not necessarily the case and if the system is not catching up and the gap is widening, even incremental change can result in excessive mismatch.

staying on a frontier where the returns to additional resources decline to zero, will marshal *internal* forces for institutional change.

If these changes can 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 provide 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 6.

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 6 Interrupted innovation

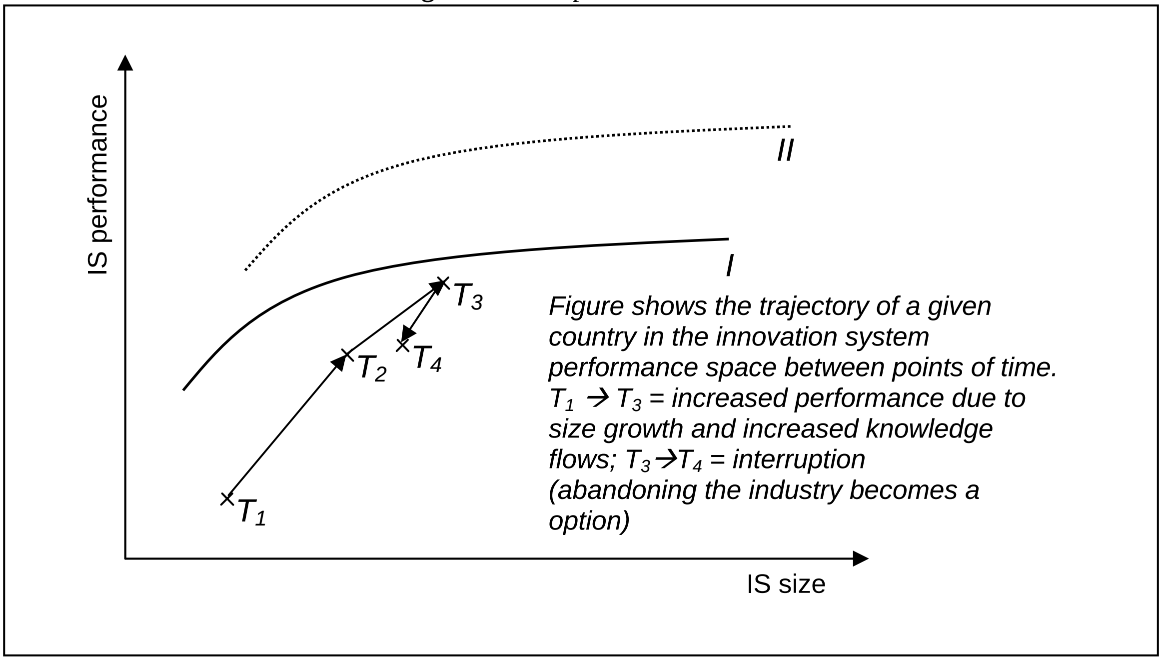
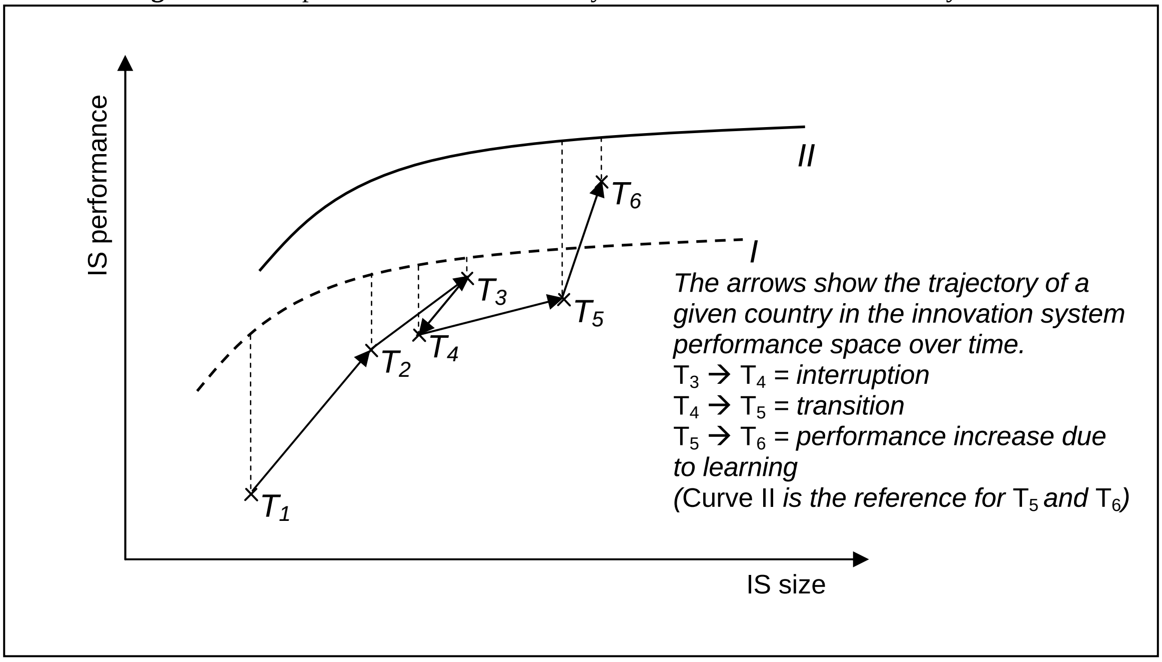


Figure 7 shows the case of a successful transition to a new system defined by frontier curve *II*. Recovery after an interruption will not immediately show higher performance even if a successful transition to a new system of innovation has been achieved. Increased performance can only be realized over 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.

Figure 7 Interrupted innovation followed by transition to a new innovation system



In Figure 8, we plot innovation system performance of a country against time on the horizontal axis, rather than against size as in the previous graphs. 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 fall in innovation performance.

In figure 8, *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.

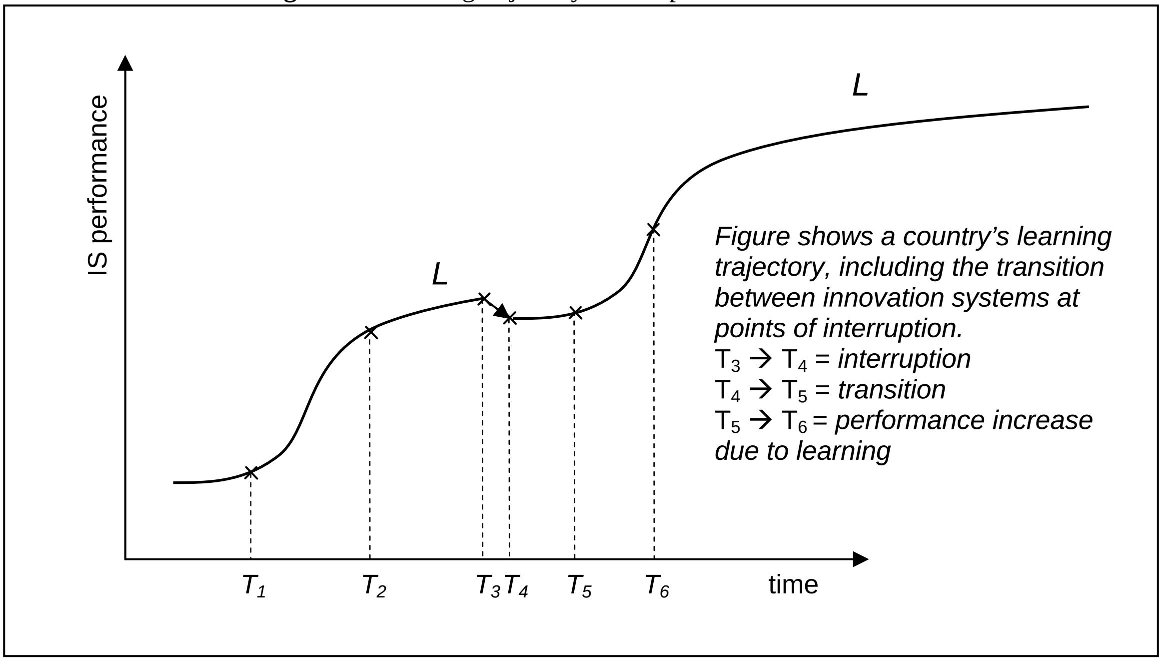
The time between the point of interruption and that of system change depends on the readiness and capability of the actors to react to changes in the environment. It is thus an indication of the flexibility and adaptability of the innovation system of an industry.

A crucial difference between well established or mature innovation systems[18] and emerging ones is the greater vulnerability of emerging innovation systems to external shocks. These shocks cause interruptions during which previously acquired

[18] Chaminade and Vang (2008) use the term ‘mature innovation systems’.

technological capabilities are lost. Even leading producers have found to be prone to 'organizational forgetting'.[19]

Figure 8 A learning trajectory: interruption and transition



4.7 *System performance and competitiveness*

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

Competition is a key driver behind 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.

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 7). They can increase their competitiveness in three ways. First, by learning within a system, which corresponds to moving closer to an existing performance frontier as shown in Figure 3. Second, by incrementally shifting the performance frontier through incremental institutional changes (Figure 4). Third, by making the transition to a new performance frontier which is superior to the previous one (Figure 5).

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

[19] Production experience can depreciate, not only appreciate over time (Benkard, 2000)

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 system governance is to find the most cost-efficient way to manage system transitions. Incremental change will not bring about as great gains as radical ones, but the costs of institutional change are much higher. 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 a global drop of demand for products, in case of crises. Competitiveness in these instances is measured by the flexibility of the industry, or its ability to respond timely to the changing demand conditions by changing 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. Also at firm level, Yuan et al (2010) showed that strategic flexibility matters; it is reasonable to assume that a first movers' advantage exists when it comes to competition of industries. The one that is set on the new path first has the highest likelihood to recover from the depth of an interruption.

4.8 *External causes of interruption*

A major difference between innovation system change at the technological frontier and in latecomer countries is the potential cause of interruption. Latecomers by definition enter an industry characterized by Schumpeter Mark II competition[20] 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 government's financing abilities. Consequently macroeconomic and political crises and changing competitive environment are all potential external causes of interruption and have a far greater likelihood of causing interruptions than endogenous technological ones.

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

In the following section we present four 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

[20] '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).

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 examine the following analytic questions in the country case studies:

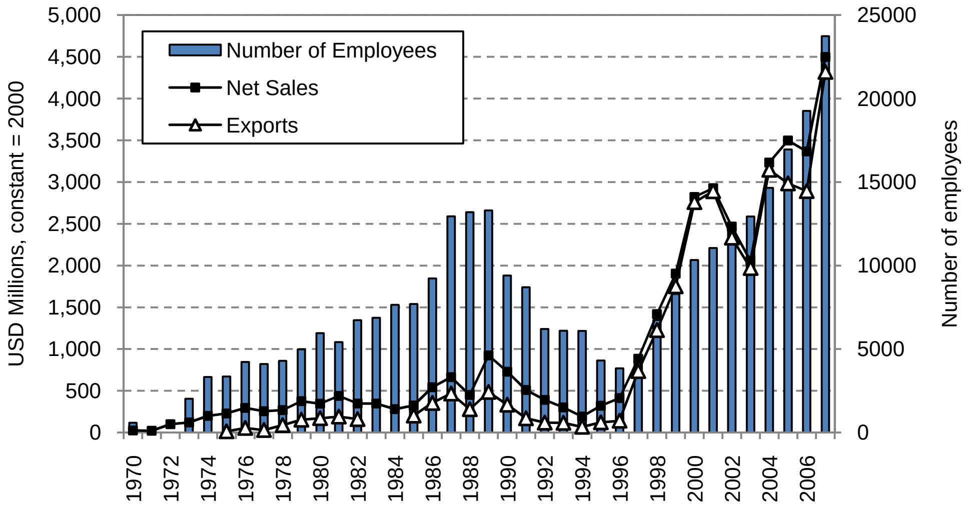
1. What trajectories did the latecomers in aerospace follow?
    a. How can these trajectories be measured and analysed?
    b. To what extent is the end of the emergence phase associated with interruptions and transitions?
2. What caused the interruptions in the development of the sectoral innovation system? What is the balance between internal endogenous sources of interruption and exogenous system shocks?
3. What were the characteristics of the transition period?
    a. How did interruptions and transitions affect the accumulation of latecomers' technological capabilities?
    b. Who where the actors governing the transition period?
    c. What were the factors contributing to the success or failure of transition from one innovation system to another?
    d. Are there ways in which 'transition-institutions' can minimize the negative effects of interruption causing erosion of capabilities in an innovation system?

5 Brazil[21]

5.1 *Introduction*

In 1969 a state-owned enterprise, Embraer was established by a presidential decree to produce and market commercial aircraft. By 1980 the company has grown to nearly 6000 employees and has manufactured over 300 of a locally designed 15-19-seater twin-turboprop aircraft, the *Bandeirante*, more than 400 of a single-seater agricultural piston plane, the *Ipanema*, and launched the pressurized executive twin-prop, the *Xingu*. In 1981, the company earned some 190 million US dollars from exports, and nearly 440 million dollars from sales (Figure 9), and made a profit of 26.5 million dollars.[22]

Figure 9 Embraer's sales, exports and number of employees, 1970-2007.
(Million USD at constant = 2000 prices)



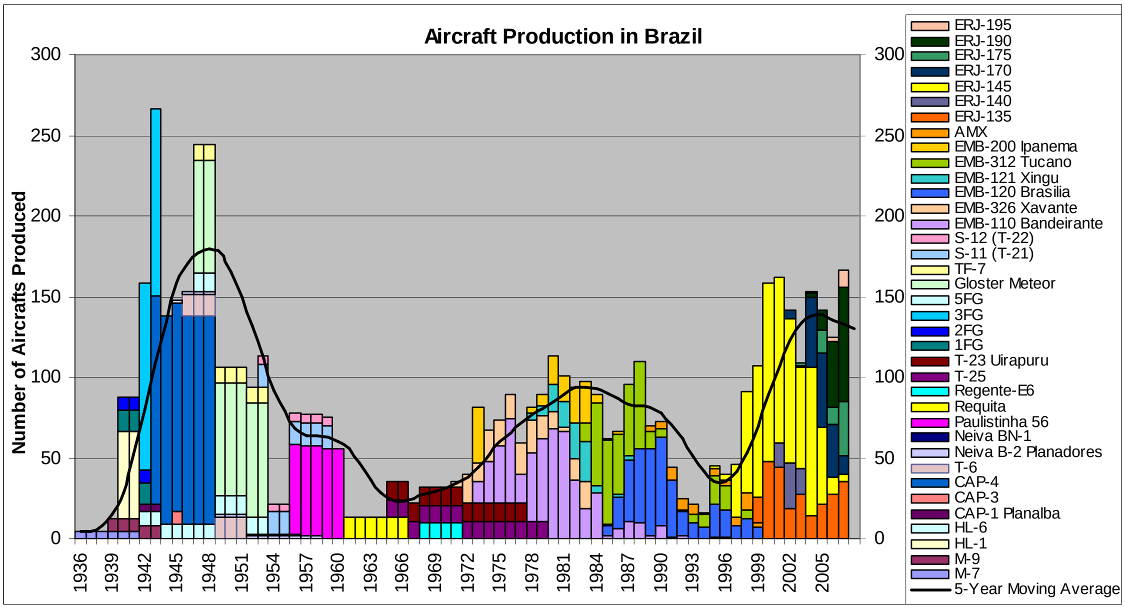
Sources: Embraer, Frischtak 1992, Ramamurti 1987, Cassiolato 2002.

5.2 *The emergence of a sectoral innovation system*

The successful launch of Embraer marks the end of a transition period. The Brazilian aircraft industry was in a crisis after the Second World War. During the war Brazilian factories produced hundreds of small military trainers for the Allies (Figure 10). By the end of the 1940s the competition of technologically more advanced US producers drove the four local aircraft factories[23] out of business. Why did it take over 20 years before a new company could emerge from the ruins?

[21] The case of Brazil and the history of Embraer has been widely discussed in the innovation systems context (to highlight but a few studies, c.f. Cassiolato et al 2002, Marques 2004, Marques and Oliveira 2009).
[22] Figures are from Ramamurti (1987); values adjusted to constant 2000 US dollars.
[23] The four companies were The National Air Navigation Company (CNNA), Companhia Aeronautica Paulista (CAP), Fabrica de Galeao and Fabrica de Avioes de Lagoa Santa.

Figure 10 Aircraft production in Brazil



Source: own compilation based on Cabral (1987); Cassiolato *et al* (2002), Embraer Annual Reports, The *Airlinerlist* database <http://www.airlinerlist.com> (downloaded 2009 Feb); *Flight International*, various issues.

Note: When exact annual production data are lacking before 1969, we divided the total number produced by the years of production.; Embraer Legacy executive jets are included in the ERJ-135 series; figures after 1970 exclude general aviation aircraft, including license-produced Pipers and the upgraded versions of the Ipanema (EMB-201 and 202).

First, there was a lack of overarching strategy on how to develop the sector. It was clear that Brazilian firms did not possess the capabilities to produce what was locally demanded. Previous experience in producing small, propeller-driven planes was insufficient to meet the demand of commercial aviation for larger planes to serve transcontinental routes and smaller passenger planes to provide access to the vast inland areas of Brazil with poor airport infrastructure. The military needed planes to provide effective control of the country's airspace and train pilots. The provision of trainers was easier to meet making use of existing capabilities. However, the benefit of local production over importing planes from more efficient and thus cheaper suppliers was debatable. The sheer size of investment required for educating and training the required human capital, for machinery and equipment, or to develop new designs explains partly why the government was hesitant in outlining any strategy and appropriating large sums in the budget. Nevertheless, the establishment of the Technology Institute of Aeronautics (ITA) and the Aerospace Technical Center (CTA) or the procurement of a team of German aeronautical engineers in the early 1950s indicated the government's dedication to maintain and improve technological capabilities in the field of aeronautics[24] and pleased those lobbying for a grand strategy to develop the industry (among them industrialists in the states of Sao Paulo and Rio de Janeiro, and officers, pilots and aircraft engineers from the Brazilian Air Force (FAB)).

[24] ITA not only provided a constantly growing, well-trained stock of aerospace engineers and techniciansm, but also maintained active linkages with leading foreign technical institutes, ever since MIT faculty assisted its establishment.

Second, the accumulation of technological capabilities always takes time. The constant flow of graduates from ITA as well as the arrival of experienced European aircraft designers[25] with new ideas contributed to increased experimentation with small aircraft designs mainly at CTA's R&D department (IPD) and at a very few private enterprises. However, aircraft design remained a small-scale activity, relying mostly on limited military orders. Production and maintenance activities could only keep two private light-plane producers in business, Aerotec (a spin-off of CTA) and Neiva. Producers did not take part in global competition and remained well behind the technology frontier in their market segment. Capabilities were still not in line with the market demand. General aviation was insufficient to provide an opportunity for producers to learn to compete. Access to technology was limited to what was public knowledge (through linkages with foreign universities and research institutes) or "embodied" in skilled individuals (foreign aircraft designers).

In short, during the 1950s and 60s the basic tenets of a sectoral innovation system were established. The emergence of its main actors and linkages happened slowly and without a clear central mission. For a sectoral innovation system to reform and provide the impetus for industrial growth and catch-up, the emergence of an entrepreneur or innovation system broker was essential.

The system broker was Ozires Silva[26] and his team at CTA who played a central role in (1) finding a market niche (commuter aircraft capable of serving airports with poor infrastructure) and (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, commissioning 80 *Bandeirantes* and subsequently new planes, and a corporate tax incentive scheme channelling private capital to Embraer) and technology (through an exclusive contract with Piper or a deal with Italian producer Aermacchi, an offset contract with Northrop and collaboration with the Canadian engine manufacturer Pratt & Whitney).[27]

The empirical evidence of successful system transition is ample. On the output side, Figure 10 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 EMB-120 *Brasilia* (a pressurized 30-seater twin-turboprop commuter). Figure 9 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[28] paid off, especially after the liberalization of the US market (in 1981, *Bandeirante* had a 37.8% share in the 15-19 seat segment[29]). Brazilian

[25] Foreign designers included Heinrich Focke, who collaborated with CTA; Willibald Weber and Joseph Kovacs who worked with the industrialist Jose Carlos Neiva; or Max Holste, who helped design the first commercial plane for CTA, that became the Embraer *Bandeirante*.

[26] 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.

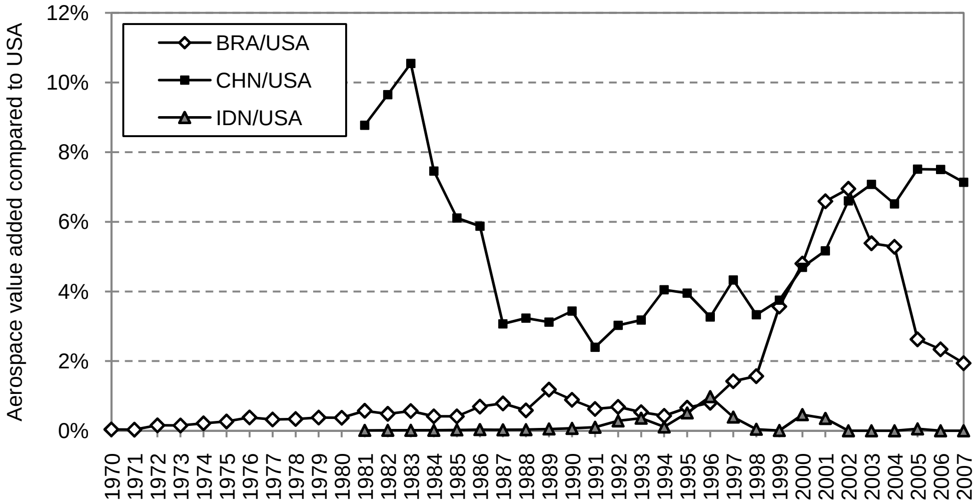
[27] (Due to space limitations, we refrain from presenting the history in greater details, but there is an extensive literature to cover these points: Silva, 2002, Cabral, 1987, Ramamurti, 1987, Frischtak, 1992, Cassiolato 2002, Embraer.)

[28] 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.

[29] Sarathy, 1985

aerospace value added grew to 220 million by 1980 and 790 million USD by 1989. This growth is especially remarkable contrasted to the global industrial landscape, shaken by the oil crisis. 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% growth between 1981 and 1989 still overshadows the global average of 122% (and 125% of the USA), providing a clear evidence of catch-up (Figure 11).

Figure 11 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.

We argue here 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 the increased sales performance and growth. However, the physical and human resources and the general institutional arrangement for performing innovative activities were available before the creation of Embraer. The government and other systemic actors provided key elements such as affordable skilled labour, R&D activities (and results which Embraer commercialized), openness to foreign technological sources, practices of military procurement for new aircraft development and export credits, or protectionist trade policies.

The establishment of Embraer as a state-owned enterprise[30] was the final institutional innovation in the formative phase of the SIS. A national champion allowed Brazil to reap the benefits of an already existing SIS 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 (*ibid*) aptly refers to as a combination of public power and private initiative – was in fact the result of shared governance of the innovation system. Certain functions (following the typology of Hekkert et al, 2007), such as 'knowledge development', 'knowledge diffusion' were shared between CTA and Embraer's R&D departments or foreign sources. 'Guidance of

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

search' for new technologies and 'market formation' were jointly influenced by the marketing strategy of Embraer and the procurement policies of the Air Force or the Aeronautical Ministry. The government played a more 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.[31]

This governing structure remained in place until the next major transition of the SIS. Over the years as production increased smaller adjustments or iterations 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.

5.3 *The Crisis*

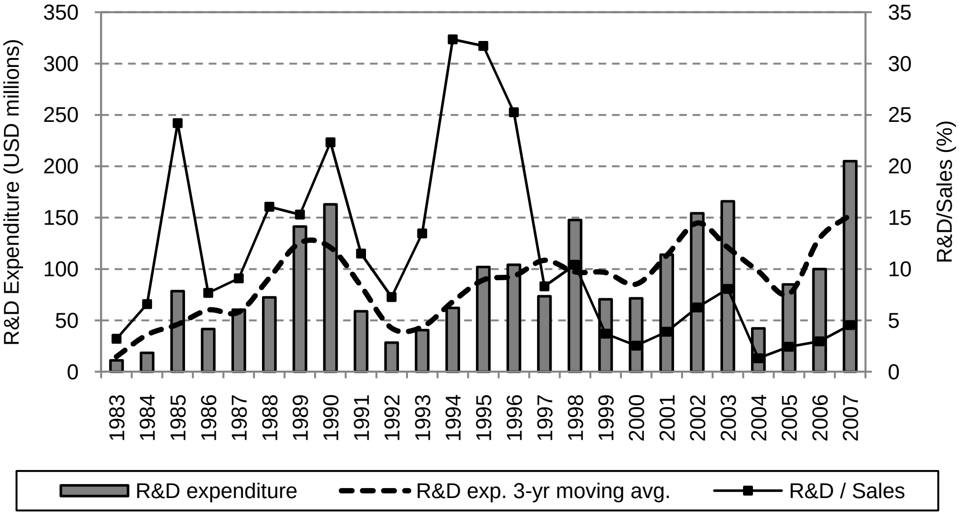
The period 1990-94 marks the second crisis of the Brazilian aircraft industry. While global recession caused value added for the global aerospace industry to decline by 30%, Brazil was hit more severely. Sales plummeted by some 75% and export by 80% from the level of 1990. Figure 10 reveals not only the reduced production of the EMB-120 *Brasilia*, but also a gap where no new aircraft was introduced to the market. This therefore indicates a crisis of the innovation system. [32]

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 12). The company had to reduce its workforce to less than half the 1989 levels.

[31] 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.

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

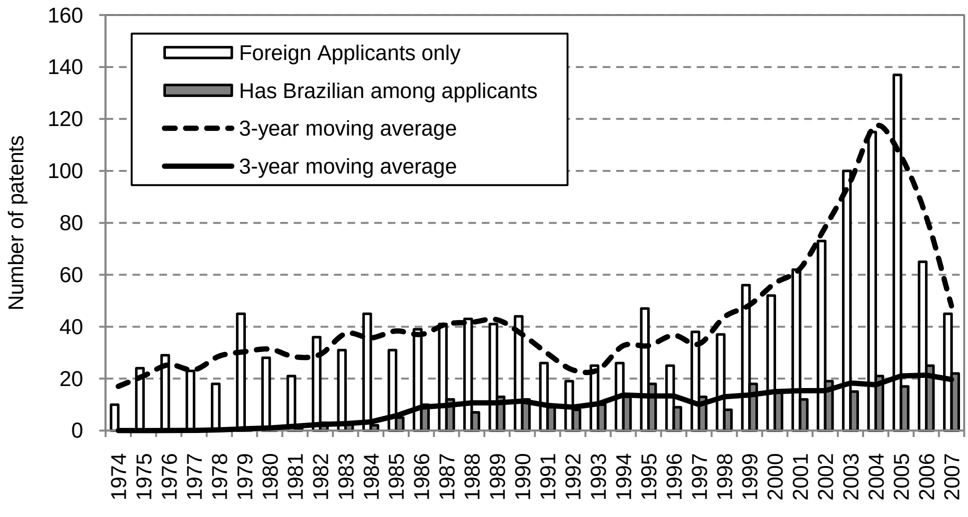
Figure 12 R&D Expenditure and R&D intensity of Embraer, 1983-2007
(Million USD at constant = 2000 prices)



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 SIS (Figure 13). Although patents are less appropriate measure of innovativeness in the aerospace industry[33], the trend of foreign companies patenting[34] 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 13), followed by a sharp, four-year interruption.

Figure 13 Number of patents in the field of aerospace granted by year of application (1974-2007)



Source: Brazilian Patent Office via Esp@cenet

[33] Patents are less meaningful indicators in the aerospace industry as compared to other high-tech industries such as biotech, since innovations are preferred to be protected by secrecy (Niosi and Zhegu, 2005), which is a rather efficient way given the high capital barriers.

[34] 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.

By that time, the technological challenges of aircraft manufacturing changed from priorities of economy and fuel efficiency to cost, noise and capacity (Sehra and Whitlow, 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 of high commonality between models. 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 industry lost its competitive edge and the innovation system was not able to help it regain.

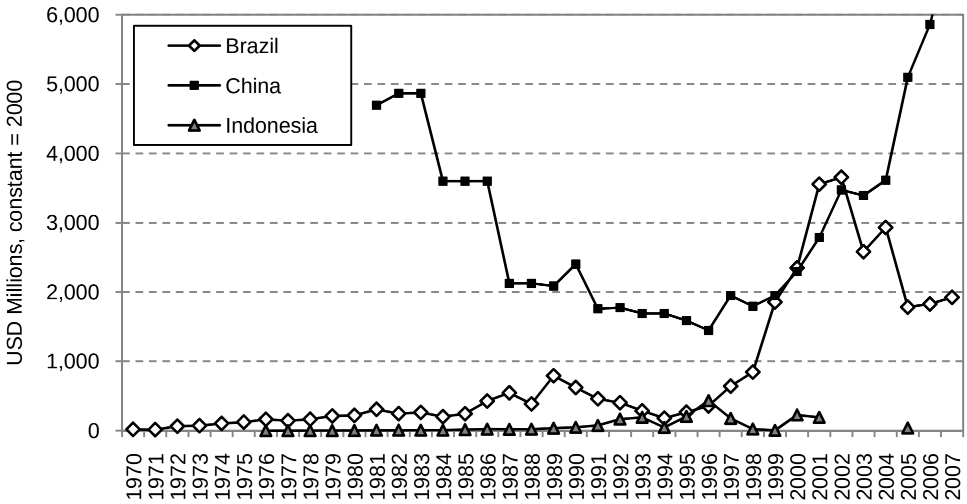
5.4 *A radical change in the Brazilian sectoral innovation system*

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 domestic investors. Although the government did not use military procurement for launch support, it continued to fund part of Embraer's R&D activities and exports[35] (through FINEP, BNDES and Banco do Brasil). At the same time, spin-off enterprises (with former Embraer employees) joined the local supplier chain. Privatization resulted in capital injection as well as in greater flexibility to sign partnership agreements to jointly develop a family of regional jets. Risk-sharing partnerships (see Figueiredo *et al*, 2008) reduced R&D costs for Embraer and became an important new source of technology. Embraer changed redefined its core competence as aircraft designer and system assembler.

The results of these institutional changes are 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 14). At the same time while Embraer's R&D expenditures increased, the R&D/Sales ratio decreased from over 30% to less than 5% (Figure 12), even though Embraer was developing a new family. 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 line. Embraer introduced over a dozen new models of regional and executive jets since the system transition and became third largest manufacturer of jet aircraft worldwide in terms of delivery.

[35] 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 (see Goldstein and McGuire, 2004).

Figure 14 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 (Vertesy and Szirmai 2010); CNY/USD: 4.6 (Szirmai *et al*, 2005); IDR/USD: 4201 (Stuivenwold and Timmer, 2003).

5.5 *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.[36] There are several signs of shortcomings of the SIS 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 development and procurement policies or offset agreements targeting the supplier chain to create a globally competitive center of excellence in aerospace.[37] 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. Latest large civilian aircraft designs use composite materials at an unprecedented scale,

[36] For a discussion of trends in value added and labour productivity, see Vertesy and Szirmai (2010).
[37] Clearly indicated by recent detailed, comprehensive studies, see ABDI (2009) and Montoro and Migon (2009).

in which Embraer is lagging behind.[38] 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).

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. The changes in innovation system size and performance are charted in Figure 15 within an interrupted innovation framework.

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.[39]
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 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 size and performance increase was once again not linear (with a significant break in 2002-3), but overwhelmingly positive.

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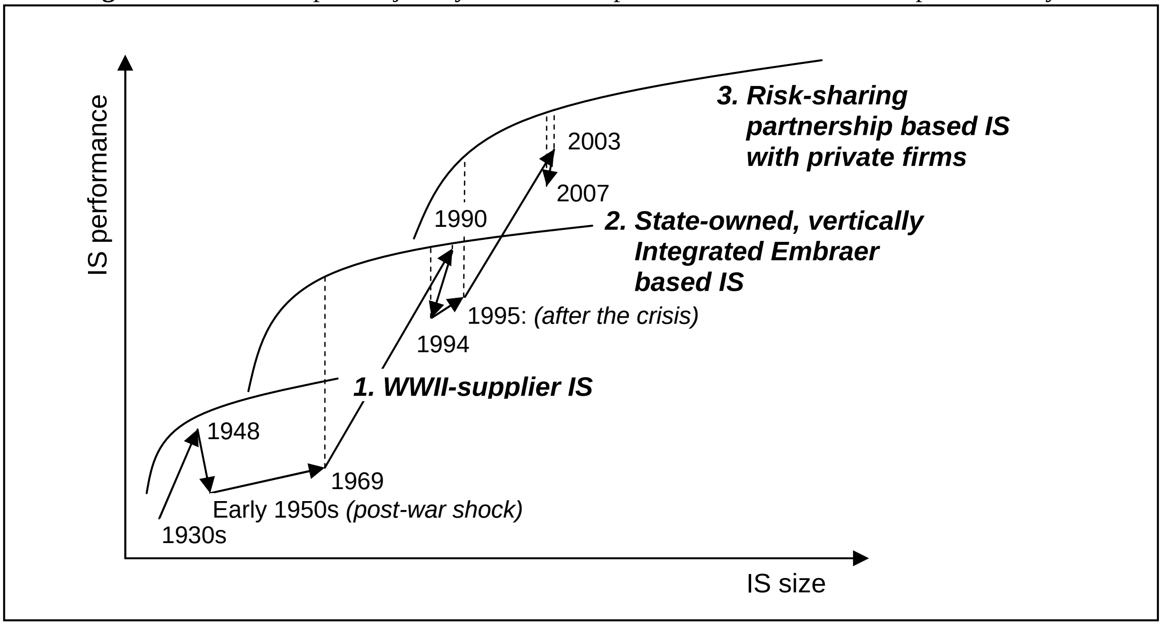
[38] When deciding for the use of composite materials, there is of course a tradeoff between production and spare-parts costs and operating costs.
[39] See Marques 2004 for more details on the system.

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.

Figure 15 The interrupted trajectory of the development of the Brazilian aerospace industry



Source: Authors

6 China

6.1 *Introduction: from military to civilian innovations*

After entering the aircraft manufacturing industry in the 1950s,[40] 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)

A case of system transition. In this section we focus on the lengthy crisis and 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.

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

6.2.1 Legacies of the Military-Industry Complex (MIC)

Although China at its peak in 1974 produced over 500 aircraft per year, these were always at least a generation behind the global technology frontier 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 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.

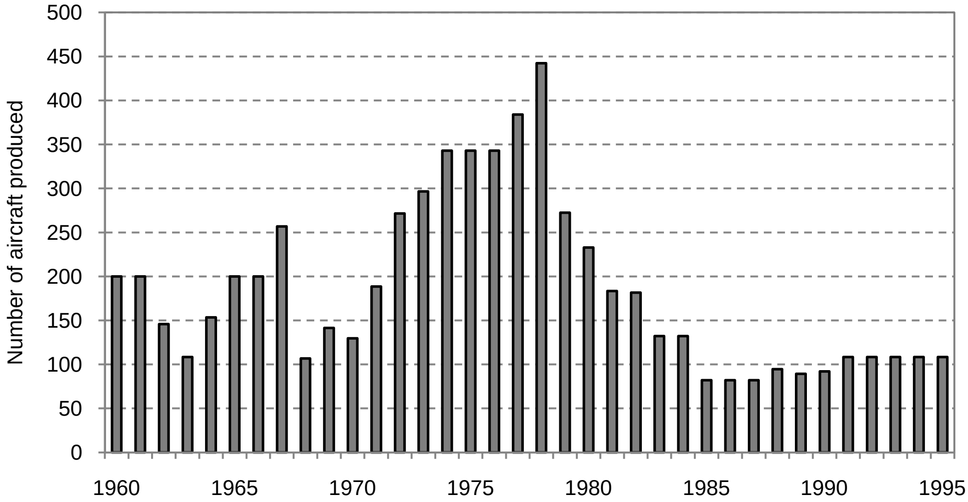
Supervision and coordination of R&D and production activities was the responsibility of the Commission on Science, Technology and Industry for National Defence (COSTIND), a body reporting both to the People's Liberation Army (PLA) as well as to

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

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 16).

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).

Figure 16 Estimated Chinese Jet Fighter Production, 1960–1995



Source: Allen et al (1995, Fig.17, p.162)
Note: 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.

6.2.2 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.[41] 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.[42]

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

[41] 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.
[42] 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.

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[43] 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 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.

6.2.3 Main features of the innovation system[44] before the changes of the 1990s

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[45] 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.

6.3 *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 large. After the end of the Cold War Chinese fighter and transport planes would not sell on foreign markets, not even in the Third World countries. Producers were lacking knowledge, skills and financial capacities to participate in higher tiers of the newly forming, vertically cooperating global industry. Due to lack of intensive interaction with producers on the technology frontier, aeronautics and astronautics education lagged behind the West. At the same time, the demand for commercial aircraft in China grew sharply.

[43] 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.

[44] 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.

[45] 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).

6.4 *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.

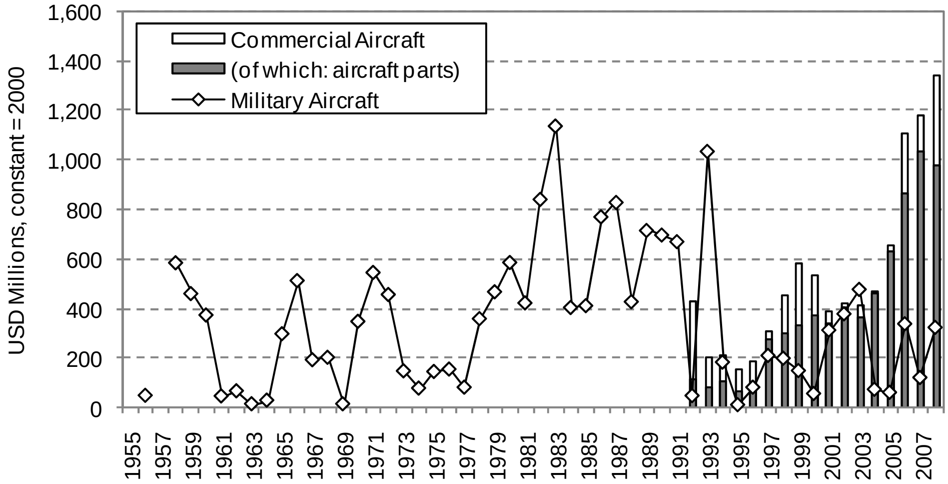
Demand for air travel spurred by growth of the economy has been a major driving factor of industrial change. Both international and domestic air traffic have increased dramatically since the late 1980s.[46] However, the Chinese air transport market remains tightly regulated and aircraft load factors and flying hours remain suboptimal, airport capacities underused (Goldstein, 2006).

6.4.1 Empirical evidence of interruption and transition

Value added. We estimate that aerospace value added exceeded 4.8 billion dollars in 1983. Following a sudden drop in fighter aircraft production, it fell to 2.1 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 2007, it reached a historic 7.1 billion USD (Figure 2).
Exports. 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 billion USD by 2007 (Figure 17). Nevertheless, China continues to import almost all of its commercial aircraft[47];

[46] 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).
[47] Import (of mostly complete aircraft) grew from 1.6 billion in 1992 to over 8.4 billion USD in 2006.

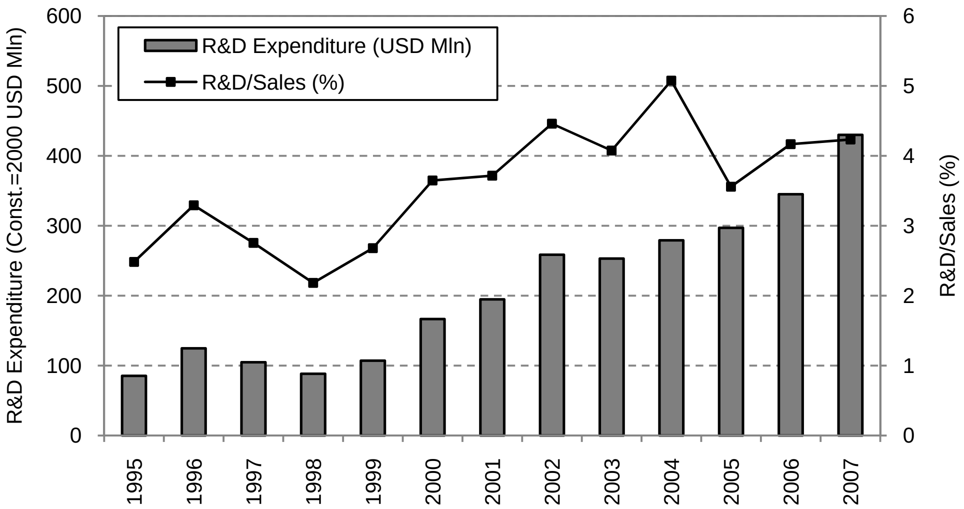
Figure 17 Export of Chinese Military and Commercial Aircraft, 1955-2008
(USD Millions, Constant = 2000)



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

R&D. Data on aerospace R&D is available from 1995. From an annual average of 100 million USD until 1999[48] the launch of major national aircraft development projects led by 2007 to an increased R&D expenditure of 430 million USD[49]. Comparing industrial R&D expenditure to aggregate sales shows relatively little fluctuation and an increasing share of R&D (Figure 18).

Figure 18 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).

[48] For a comparison, during the same period Embraer alone spent the same amount on R&D.
[49] In comparison, in 2000 the US spent a total of 10.3 billion USD on aerospace R&D, and 14 billion in 2006.

6.5 *The new Chinese aerospace innovation system*

6.5.1 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.[50] Production quality increased substantially as a result of these deals since Chinese suppliers had to deliver according to the same strict standards as other producers faced in the West. 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, 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[51] of 2003 allowed the Brazilian company to deliver ERJ-145 regional jets for the Chinese market by avoiding import taxes while acquiring 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[52] 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.[53] The Chinese government is hesitant since it 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.

Airbus also established a joint venture for final assembly in China.[54] 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.[55] The total investment in the Tianjin FAL amounted to 1.47 billion USD[56]. 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.[57]

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

[51] 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).

[52] "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/)

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

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

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

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

[57] 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

6.5.2 'Indigenous' aircraft development

Chinese ambitions to boost the industry have been high. 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.[58] 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)[59], the four plants involved (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[60]. 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.[61] 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 indicates 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[62] in the 168-190 seats category. The COMAC C-919[63] 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.

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costs for local labor force and the cost of expatriates (125 of the 500 employees). ("Airbus' China Gamble" *Flight International* 28 October 2008)

[58] "Official identifies eight goals for China's aviation, aerospace industry", *BBC Monitoring Asia Pacific*, 9 Nov 2006

[59] 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 commercial aircraft. In 2009 the company became part of COMAC, the 'Commercial Aircraft Corporation of China Ltd' established in 2008.

[60] 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*.

[61] 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.

[62] '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.

[63] 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).

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[64] 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)[65]. 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 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*[66] with regard to the development of a fifth generation stealth fighter.

6.5.3 Organizational changes

These developments in the accumulation of technological capabilities were set against a dynamically changing organizational structure. The first sign of opening up the MIC 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). Driven by the need to plant the seeds of competition, AVIC was split into two in 1999[67]. Duplications and a lack of transparency and unclear assignment of responsibilities still remained in the system which eventually led to a 2008 decision to once again merge the two. One clear result of these bureaucratic twists is a drastic decrease of employment. As Figure 19 shows, employment in the industry shrunk in a decade from some 600,000 in 1995 by half to a stable 300,000. Labor productivity increased from 1995 to 2000 by 87%, between 2000 and 2007 by 366%. These are evident signs of consolidation in the industry, even if this might not remain the final setup. Nevertheless the structure remains "extremely complex" with cross-ownership and a long line of cascading subordinates (Nolan and Zhang, 2002). Non-aviation business still makes up 80% of AVIC's business (Medeiros, 2005).[68]

[64] 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)

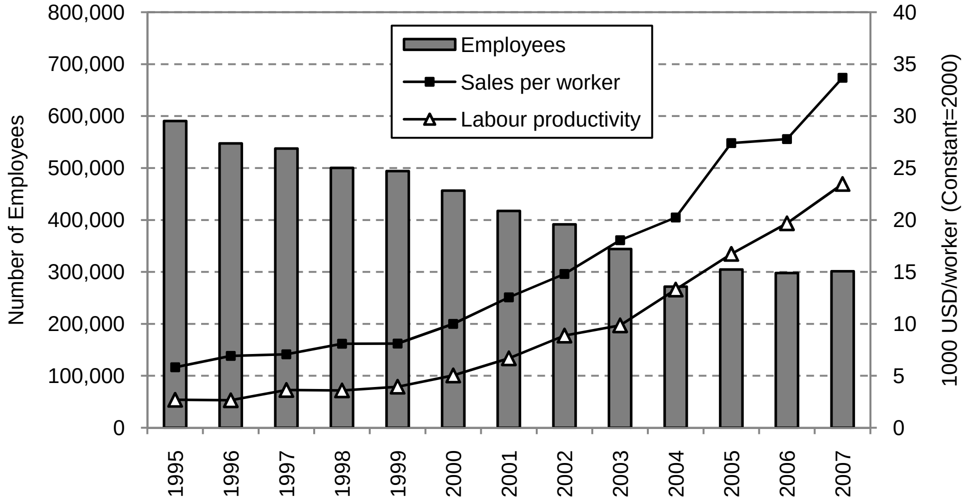
[65] The aircaft's Pakistani designation is JF-17 *Thunder*, and development partners included Chengdu Aircraft Industries Corp., the Pakistani Air Force and Pakistan Aeronautical Complex; is equipped with a turbofan engine from the Russian Klimov. Design began in 1994 but the aircraft first flew only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

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

[67] In general, AVIC I was responsible for producing larger planes, AVIC II for smaller, including helicopters. For details on the distribution of companies within, see Table 3 and 4 in Andersen (2008). CASC was also divided in 1999 into China Aerospace Science and Technology Corporation (also CASC, in charge of the space programs) and China Aerospace Machinery and Electronics Corporation (CAMEC), later in 2001 renamed China Aerospace Science and Industry Corporation (CASIC).

[68] Nolan and Zhang reports that automobiles, components and motorcycles alone accounted for 62% of AVIC's revenue in 1997.

Figure 19 Employment and Labour Productivity Growth in the Chinese Aerospace Industry, 1995-2007 (Thousand USD at constant = 2000 prices)



Source: CNBS,
Note: for value added figures see notes of Fig.14.

6.6 Interrupted innovation in the Chinese aerospace industry

6.6.1 Summary of the transition

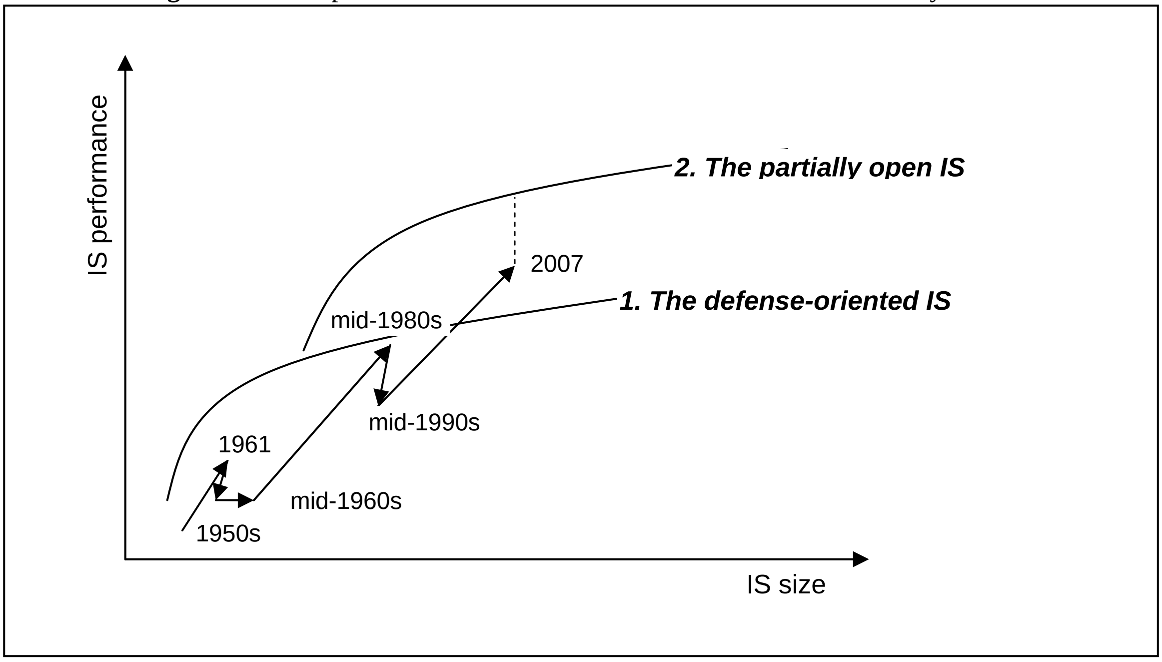
The crisis of the inward-looking innovation system was caused by exogenous political and macro-economic changes in the environment in which endogenous forces played little if any role. The interruption can almost entirely be explained by China's transition into a market economy. Yet the speed of the 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. As the export of military planes dropped, parts and components slowly replaced and overtook them (Figure 17), revealing a greater integration in global supply chains. Increasing labor productivity since 2000 (Figure 19) 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 used 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 techno-nationalist rhetoric remains in place. However, foreign ownership of private enterprises is only allowed in a limited fashion 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 affected mostly 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 to even 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.

The evolution of the innovation system and the interruption is summarized in Figure 20. 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 graph 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 is 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 invested. 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).

Figure 20 Interruptions and transition in the Chinese aircraft innovation system



Source: the authors

6.6.2 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.

1. Ownership: Decision making in the state-owned conglomerates remains slow and heavily laden with politics; 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.[69] 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 incentives for the rather well-cushioned R&D institutes. Interaction between users and innovators are still less intensive. It is unclear how much freedom various plants and R&D institutes have in defining the direction of research for 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.[70] 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 a rate faster than that of 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.

[69] 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.

[70] 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)

7 Argentina: The case of a languishing aerospace innovation system

7.1 *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.[71] 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). In 2003 value added was 70 million USD, equal to less than 3% of Brazilian value added (Table 1).

Table 1 Comparison of Argentina's Aerospace Value Added, selected years (Million USD 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 4201.2.

Since its founding in 1927, the plant giving home to aerospace manufacturing and related activities in Córdoba has often changed name, internal organizational structure and external dependence. Table 2 provides an overview of the changes in scale and name.

[71] 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" (2007:344). 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).

Table 2 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 Estado	(IAME)	9,550	n/a
1957	Dirección Nacional de Fabricaciones e Investigaciones Aeronáuticas	(DINFIA)	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 Aeroespaciales	(FAMA)	~3,000[a]	n/a
1991	Area de Material Córdoba	(AMC)	n/a	n/a
1994[b]		(AMC)	2,200	n/a
1995	Lockheed Martin Aircraft Argentina S.A.	(LMAASA)	1,250	~220,000
2002		(LMAASA)	900	n/a
2010	Fabrica Argentina de Aviones	(FAdeA)	1,100	~220,000

Source: Own compilation based on Arreguez (2007); Arroyo Arzubi (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[72].

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

7.2.1 The emergence of aircraft manufacturing in Córdoba

The Fábrica Militar de Aviones (FMA, Military Aircraft Factory) was established in Córdoba in 1927,[73] 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 3). Licenses 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 3), 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,

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

[73] 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.

Argentina declared itself neutral during most of the war. Argentina was therefore not receiving post-war aid from the US and cheap supply of aircraft, which, ironically, meant that its aircraft industry did not experience the post-war crisis that hit Brazil until 1960.[74] Fueled by the isolationist economic and foreign policies of President Perón, the aircraft industry was designated 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.*[75], 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.

Migrant European aircraft designers (linked to 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 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.[76] 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 US.

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[74] 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.

[75] 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".

[76] 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'.

Table 3 Serial Aircraft Production in Argentina

Aircraft Model	Type	Engine	First Flight[a]	Number 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.

The failure of the *Pulqui II* project has 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 local workforce 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 US 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 services[77], passenger air routes were established in the 1930s. Joint stock companies of regional airlines formed in the 1930s were nationalized in 1949 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), the most significant domestic competitor was Austral. 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.

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)[78] 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, 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.

Table 4 Cumulative stock of aeronautical engineering graduates of higher education programs in Argentina (1950-2007)

	Graduate stock			**Estimate of**
Year	**UNLP**	**IUA**	**Total**	**active stock[a]**
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.

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

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.

7.2.2 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:

- <u>Actors</u>. 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.
- <u>Institutional set-up</u>. 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.
- <u>Capital input</u>. 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.
- <u>Technology base and input</u>. 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.[79] 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.

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

- 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.

- 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 3). 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.
- Output and Market share. We estimate that by the end of WWII Argentina had produced some 400 planes (see Table 3). 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 aircraft from the US during the late 1950s it considerably reduced the high market share of locally produced military planes.

7.3 *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[80] 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.[81] 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[82] 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 productions were separated. Tank and his team abandoned work on the

[80] After 5 years in office, Perón was reelected in 1951.
[81] 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).
[82] 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).

jet fighter and other experimental designs and left Argentina in the unwelcoming political climate after the dismissal of Perón.[83]

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 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.[84]

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 was placed for the multi-purpose twin-engine propeller plane, the IA 35 *Hanquero*, but only 47 were eventually built starting from 1958.[85] At the same time the right-wing governments forged closer ties with the US and signed deals to procure US trainers and fighters.[86] 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 much of the resources from 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 was marketable abroad. New prototype development was largely discontinued. As there was no strategic aim to make the Argentinean production competitive, the technological capabilities started to erode from the 1960s onwards.

7.4 *Interruption without transition*

7.4.1 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

[83] Tank himself went to India in where he designed a jet fighter-bomber, the *Marut* for Hindustan Aeronautics.
[84] Space research culminated in 26 rocket launches between 1961 and 1981.
[85] 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 3).
[86] 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.

actors in the system,[87] 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,[88] but instead attempts were made to sustain the industry without major institutional changes. The industry and innovation system were still emerging and lacked important actors, including private firms, education and training institutes, but most importantly, a development strategy combining industrial, science and technology and education policies. It follows that both the size (lack of technology and financial inputs) and the innovative performance (very few new designs created) of the system decreased.

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

7.4.2 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 the Córdoba plant has 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. In Brazil a "public entrepreneur"[89] emerged to fill the gap of lack of strategic vision on commercialization. The reason why such a turn 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

[87] 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.
[88] 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.
[89] 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*.

emergence of such an entrepreneur. First, the Argentinean aerospace "enterprise" was a military installment 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.

Table 5 Military aircraft import to Argentina (1950-2009)

Types	Model	Year	Number of 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 Corsairs	1956-58:	62	USA (used in WWII, Korean War)
	F-9F Panthers	1957-58:	20	USA
	F-86 Sabres	1960:	28	USA
	F-9 Cougars	1962:	2	from the US; although did not receive spare parts for the plane later… mistakenly Argentina became the only foreign recipient of these planes
	A-4P ground attack Skyhawks	1966-7 1970 1972 1976 1997	25 25 16 25 36	USA (28 of which modernized locally)
	Mirages	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
Multi-purpose transports / coast guard	CASA C-212	1989-90	5	Spain

Source: SIPRI

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 5 for an overview of imported aircraft.)

7.4.3 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 80s.

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 *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)[90]. According to the published specifications, the *Guarani II* outperformed aircraft in its league. It could fly higher, faster and further than Embraer's star, the *Bandeirante* (see Table 6).

Table 6 Main features of the *Guarani II* in comparative perspective

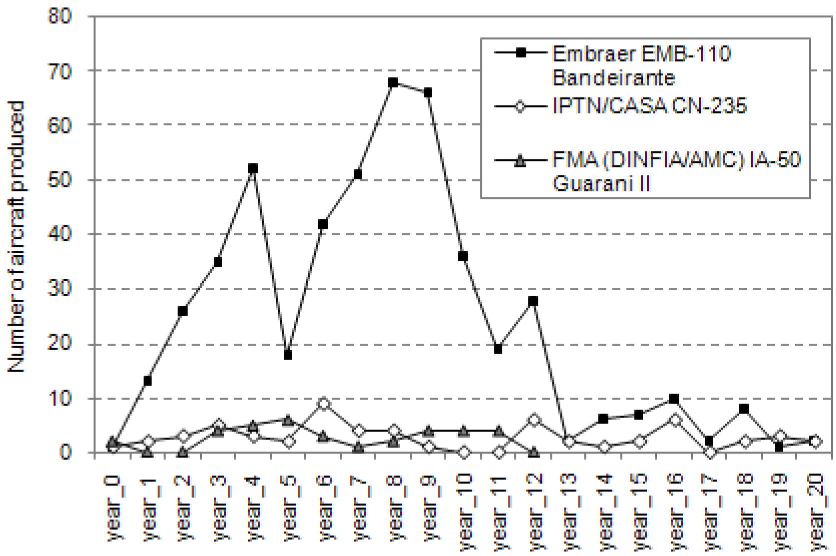
	DINFIA IA 50 *Guarani II*	Embraer EMB-110 *Bandeirante*	CASA C-212 *Aviocar*
Capacity (crew+passengers)	2+15	2+21	2+26
Dimensions (m): (length/wingspan/height)	14.9 / 19.5 / 5.81	15.1 / 15.4 / 4.9	15.2 / 19.0 / 6.3
Empty weight (kg)	3,924	3,500	3,700
Maximum takeoff weight (kg)	7,120	5,900	6,300
Power 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

[90] Source: "Guaraní" *Aeromilitaria.Com.Ar*
URL: http://www.aeromilitaria.com.ar/ind/aviones/gii/index.htm (page last updated: 3 Mar 2007).

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[91] 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 21 shows the drastic difference in the production cycle of the *Guarani II* and the *Bandeirante*. Nothing emphasizes better the capacity of the newly emerging Brazilian producer to design an aircraft for commercial markets and construct it in great quantities, and the laggard position of its older Argentinean counterpart that showed more resemblance to the also emerging Indonesian plane maker.

Figure 21 Comparison of annual production of commuter-size aircraft by FMA, Embraer and Nurtanio (first 20 years of production)

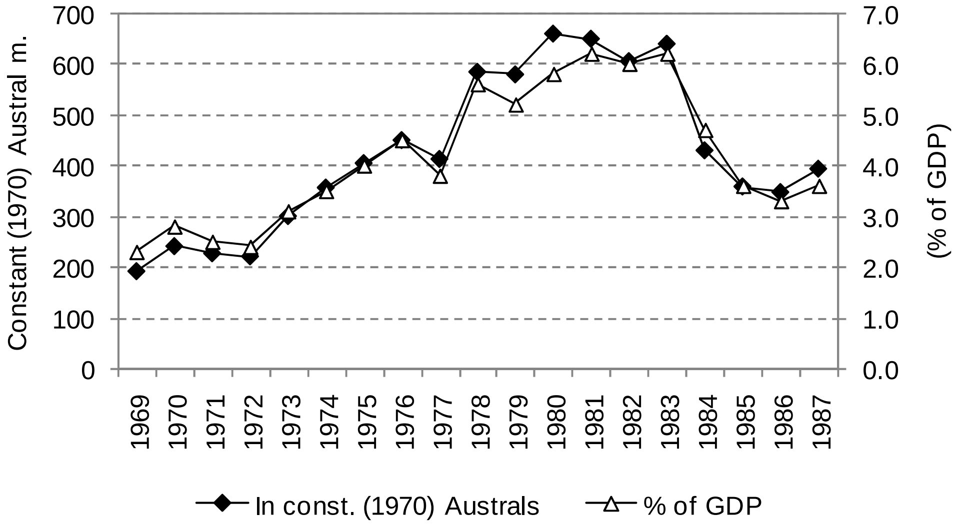


Source: Cabral 1987, Cassiolato *et al* 2002, Airlinerlist.Com, Aeromilitaria.Com.Ar
Note: The FMA and Embraer aircraft were designed and produced domestically. The CN-235 was co-designed and co-produced by CASA and IPTN; the figures presented show the number of aircraft finally assembled in Indonesia. 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 22). Details of the expenditure are not known, but the air force evidently managed to corner a large share. First of all, it should be noted that the junta's increased military expenditures were unsustainable due to the 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 larger share 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 5).

[91] The Argentinean Air Force reportedly used 29 of them, but little is known of the operating history of the plane. Aeromilitaria.Com.Ar

Figure 22 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 requirement 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 through regular market transactions.[92] Due to the limited availability of spare parts, the exported planes eventually did not collect 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 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 facilitate foreign sales) and expand existing expertise in license production, AMC signed a partnership agreement with the German manufacturer Dornier to assist aircraft development.[93] The resulting prototype of the IA-63 *Pampa* trainers showed many

[92] 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.

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

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.

7.4.4 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 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.

7.5 *Failure to radically change an ailing innovation system*

7.5.1 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*[94]. 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 US (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.[95] The government's hands were tied in the midst of monetary and fiscal troubles.

The 1994 privatization of Embraer in Brazil offered a capital injection and new source of dynamism for regional jets 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)[96], which was hardly more than a military depot seen as a burden to 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.[97] Lockheed Martin Aircraft Argentina

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[94] 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.

[95] Two prototypes were made in 1990 but the project was cancelled due to insufficient market demand.

[96] The enterprise was once again renamed to AMC in 1991.

[97] 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.

S.A. (LMAASA) assumed operations on 1 July 1995 and soon reduced the work force to 1,250.[98] Following the arrival of 8 A-4 *Skyhawks* upgraded in the US, 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 *Pampas* and produce 12 additional aircraft[99] 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.[100] 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.[101] 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 a subject of the Defense Ministry and there is little sign of any new strategy[102], new management routines or greater transparency.

7.5.2 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

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[98] "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 2).

[99] 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)

[100] 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.

[101] 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.

[102] 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.

make the industry competitive. FAMA's entering into commercial 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).

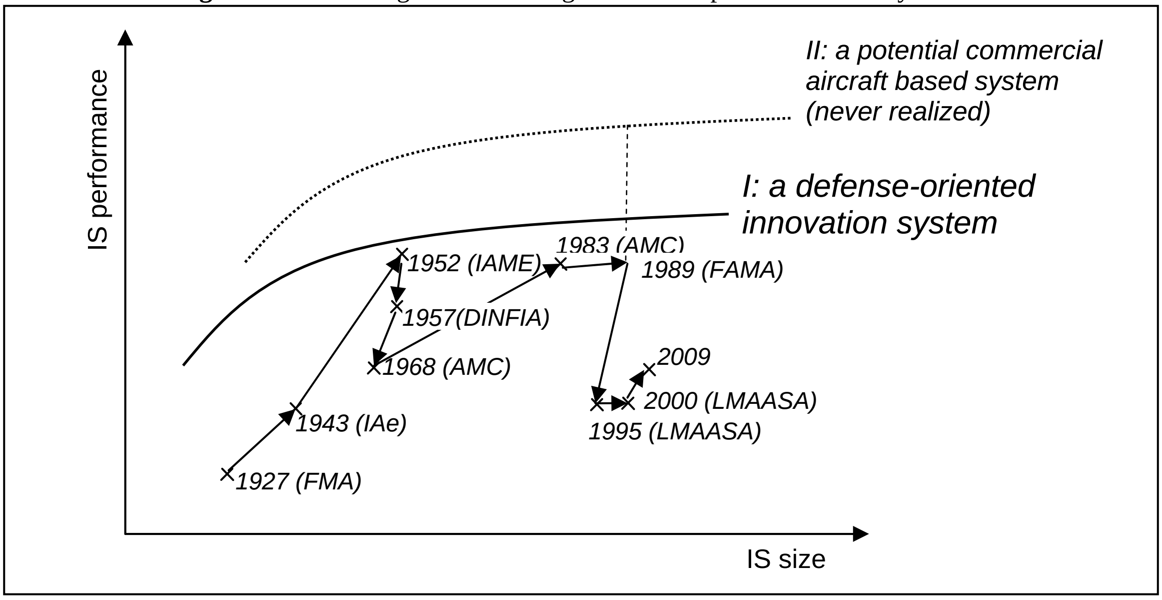
The 1995 concession deal with Lockheed Martin has stopped further decline, but did not bring system-wide institutional changes. It provided access to technology, but hardly more than earlier license agreements; and it did not even secure capital investment for technological upgrading. These were improved 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.

7.6 *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 providing 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 23. 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.

Figure 23 The Emergence of the Argentine Aerospace innovation system



Source: The authors
Note: The abbreviations in brackets indicate the name of the main organization.

7.6.1 General conclusions

Although the ideas of 1927 envisaged the construction of a factory with the long-term aim of making it a motor of industrial progress of 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, 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 of obsolete technology. All the planes Argentina imported or produced under foreign license were also near the end of their production run. Although more affordable for domestic purposes, if the aim is to acquire 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 designs and the output of aircraft with potential commercial applications will be inferior to that of a genuinely commercially oriented firm (see Figure 21).

4. An emerging innovation system and industry need 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 state financing are worthless if new governments easily cancel the ones formulated 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 innovation system transition the aircraft industry can only survive on a lifeline. At such a low performance many more decades are being lost.

8 Indonesia

8.1 *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: 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.

8.2 *The emergence of the Indonesian aerospace industry and innovation system*[103]

8.2.1 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 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,

[103] The history section relies primarily on five studies: Hill and Pang (1988), McKendrick (1992), Goldstein (2002), Eriksson (2003) and Amir (2007).

Experiment and Construction Depot (DPPP) 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.[104]

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 (IPTB), 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 aeronautical engineering studies in Europe and the United States.[105] 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 becoming a doctor of 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

[104] There is a bit of confusion in the literature, Amir dates this event 10 years earlier.
[105] 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.

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 capability was to be acquired and implemented to generate new, competitive generic technologies (Steenhuis *et al*, 2007).

Despite the lack of existing technological base and an underdeveloped capital goods sector, the Indonesian government did not hesitatate to formulate ambitious high-tech mega-projects, including telecommunications, shipbuilding, the nation car project, nuclear energy and aircraft manufacturing. The late 1960s and 1970s marked a period of rapidly growing inflow of oil revenues as a result of the exponential growth of oil production.[106] The New Order government expressed its intention to invest the oil revenues into enhancing domestic technological capabilities.

8.2.2 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[107] 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 7)

[106] Indonesian oil production increased threefold from 486 thousand barrels a day in 1965 to 1.5 million in 1976 (BP, 2009).

[107] 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).

Table 7 Key financial figures of IPTN, 1976-89. Compared with the first years of Embraer (Thousand USD at constant = 2000 prices)

IPTN														
Years	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
Employees	860	1,279	1,695	2,362	3,162	4,742	7,853	10,774	11,713	12,596	13,000	13,300	14,100	14,200
Sales	15.6	15.1	34.0	30.9	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	1.2	6.9	7.5	0.9	2.0	7.4	9.5	13.3	0.3	-16.2	1.8	0.4	5.0
Investment	49.2	19.2	11.4	23.7	41.3	84.1	141.8	139.7	119.4	79.8	205.9	85.8	42.7	54.5
Inv/Sales (%)	315.5	126.7	33.5	76.6	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	11.8	20.1	13.1	13.8	21.7	13.5	6.3	4.0	6.9	5.6	9.3	10.6	15.8
Embraer (EMB)														
	1969	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**
Employees	589	n/a	n/a	2,021	3,323	3,353	4,225	4,104	4,300	4,987	5,957	5,414	6,732	6,877
Sales		25.6	21.4	100.6	120.4	199.9	228.3	295.7	256.0	269.3	375.5	346.1	439.5	348.2
Comparison of IPTN vs. Embraer (%)														
Employees: IPTN/EMB (%)	146.0	n/a	n/a	116.9	95.2	141.4	185.9	262.5	272.4	252.6	218.2	245.7	209.4	206.5
Sales: ITPN/EMB (%)		59.2	158.7	30.7	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: Prices updated using GDP deflators from the World Development Indicators; official exchange rate for 2000: 8421.8 IDR/USD applied.

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.

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[108] 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 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 estimates[109]. 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 8 for an overview of the aircraft and helicopters produced in Indonesia)

[108] 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).
[109] While the exact numbers are some, based on data from IPTN staff 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).

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 (ibid, 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, but it was the C-212's "simplicity in design and construction" (McKendrick, ibid, 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[110]. IPTN had a license to produce 108 NC-212s and had completed 95 by the year 2000.[111] Due to a variety of reasons, 16 of these planes were involved in accidents. (See Figure 24 for an overview of Indonesian aircraft production.)

Table 8 Number of aircraft delivered and helicopters produced 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								

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.

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.

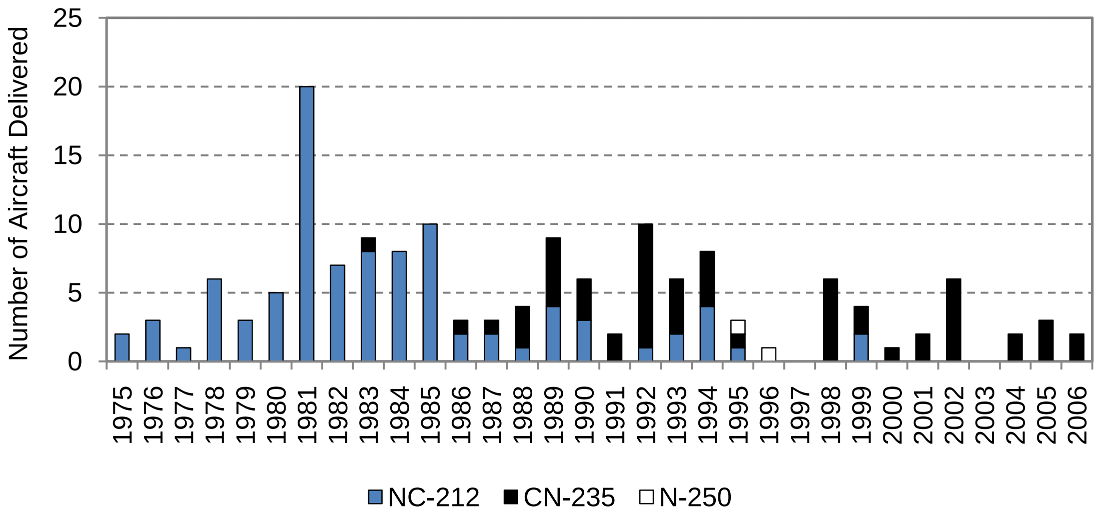
[110] McKendrick reports only 6 planes exported by 1986, 5 for agricultural use in Thailand and 1 for Air Guam; SIPRI lists only the 4 exported to Thailand.
[111] "Toughing it out", *Flight International*, 25-31 July 2000

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 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 (ibid, p.45). These parts were then exchanged and final assembly took place both in Spain and in Indonesia.

The design phase (1979-82) allowed 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 US and Europe. For IPTN, this was reduced over the years to 20 percent, although the reduction only affected the airframe.

Figure 24 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*[112]. There are reports of NC-212 production in Indonesia after 2000, but exact number and year are unknown.

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

[112] "Indonesia tries to rescue Malaysian IPTN deal" *Flight International* 24-30 Jun 1998

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 US (the US 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 to 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 cleared the market. Export 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)[113]. On the global market the (Indonesian and Spanish made) CN-235s achieved only moderate success, with around 5% share in the 20-45 seat segment by 1990[114]. By 2007 a total of approximately 234 CN-235s have been produced by CASA and IPTN together.[115] Analysts considered the realization of the CN-235 venture as a success[116] for the newly emerging industry of Indonesia and it brought significant prestige for Habibie.

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 compares rather favorably in terms of fuel consumption and range, but this comes at a cost of speed and cruising altitude (see Table 9).

Table 9 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 consumption[a] (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**

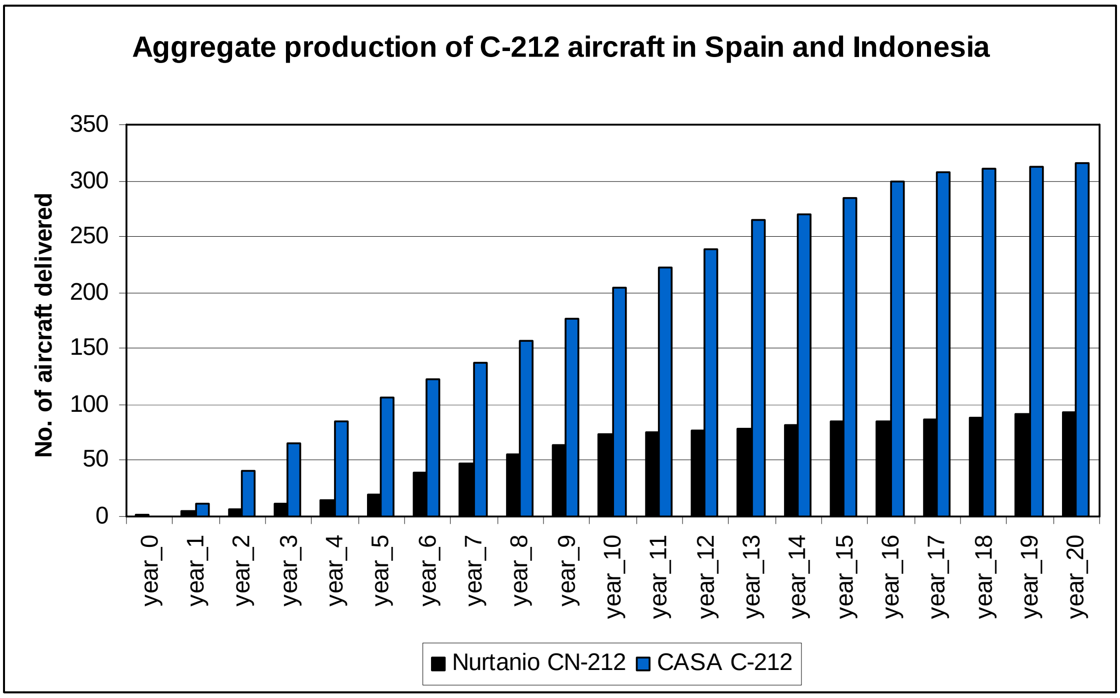
Source: Regional Airliner Directory, *Flight International* 10-16 June 1992; producers
Note: a) at long-range performance

Figure 25 and Figure 26 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

[113] Figures are based on SIPRI estimates.
[114] Goldstein (ibid, p.529 referring to Dagnino)
[115] "Status Of Programs" *Aviation Week & Space Technology*, 10 November 2008.
[116] 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.

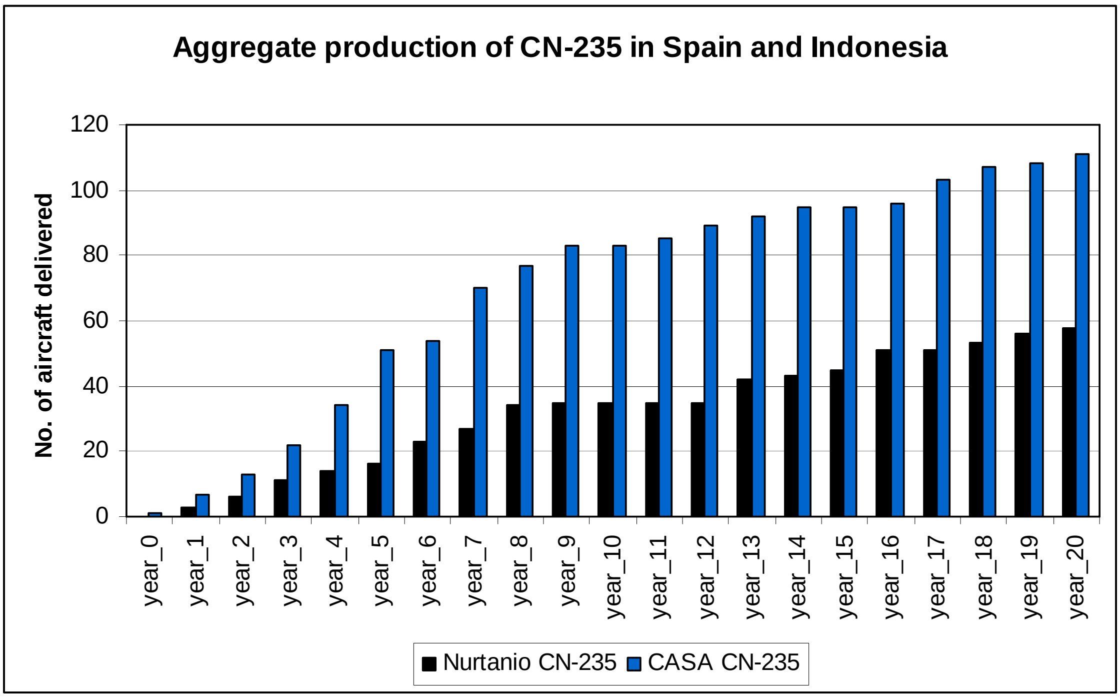
flattens out sooner (at around 90 deliveries in the case of the C-212 and around 60 in the case of the CN-235) while CASA's delivery is still growing reveals Indonesia's sales problems.

Figure 25 Cumulative production of the C(N)-212 aircraft in Spain and Indonesia



Source: http://www.airlinerlist.com (Retrieved: 16 Dec 2009)

Figure 26 Cumulative production of the CN-235 aircraft in Spain and Indonesia



Source: http://www.airlinerlist.com (Retrieved: 16 Dec 2009)
Note: Spanish production does not contain the 50 aircraft produced in Turkey under license

External knowledge flow was 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 agreements were supported by Fokker until the company went bankrupt. The collaboration with TU Delft was crucial, since ITB did not offer higher than masters level programs 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[117]. 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.

8.2.3 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 with dual military and civilian use[118]. 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 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

[117] Sources contradict on the value of the offset deal; McKendrick reports 17.7m (ibid, p.44), SIPRI reports 52m USD (ibid).
[118] Amir’s interview with Habibie (ibid, p.287)

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 grew to over 1,500. To fill the gap President Suharto decided to allow IPTN to use an interest-free loan of 185m USD from the reforestation fund[119] (and offered a 5% royalty from all sales to the Forestry Department 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[120] 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 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 9 show, the N-250 fitted more in the product lines of the 1980s than of the 1990s . While the propeller-driven commuters' market was shrinking, the novelty it offered (fly-by-wire system) was not enough to please buyers. Cross-border R&D and production ventures were the new source 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 getting saddled 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 favorable to these kinds of experiments. The influence of one strategist on determining the technological capabilities was

[119] 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.
[120] Major causes for delay were partly of organizational, partly of technological nature (including concerns with the application of the fly-by-wire system).

excessive, and correcting mechanisms, 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.

8.2.4 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:

- 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.
- 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[121] ensured a rather soft budget constraint for the company.
- 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.
- 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, 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.

[121] 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.

- 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 10).
- (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.[122] 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 10 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

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:

- 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.
- 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.
- 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.

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[122] Information retrieved from BIT's website; "Faculty of Mechanical and Aerospace Engineering, General Information and History" (www.itb.ac.id)

- 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, IPTN average sales in the first decade of production, grew slower, hardly reaching one third of the sales levels of Ebraer.[123] By 1993, IPTN's sales increased to 193 million USD. By 1996 the total Indonesian aerospace industry's value added 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.

8.3 *Crisis and interruption without transition*

8.3.1 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[124]. Had it been successful, the financing scheme of the project could have been called 'innovative'. In 1996 a separate financing company was created, PT DSTP[125], 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 production (not before 2003, according to a 1998 schedule). The company failed to raise more than around 1/20th of the required capital, no potential foreign partners showed serious interest in investing, analysts also dismissed what Goldstein (2002: 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 the aircraft industry, in return for a bail-out from the crisis, which hit Indonesia the worst among the East Asian economies (Hill, 2000). Even Habibie becoming president of Indonesia in May 1998 for over a year could not provide more funds for the industry, which by 1999 accumulated 570m USD in debts (Goldstein, 2002). In September 1999 DSTP was dissolved, the investment into the N-2130 aircraft was written off as sunk cost.

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[126]. In response to the crisis, IPTN was diversifying into non-aviation related

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[123] 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.
[124] 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 2002 footnote 2 p 530 for a more critical interpretation.)
[125] 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.
[126] "IPTN Phoenix falls before Australian competition decision" *Flight International*, 8-14 Jul 1998

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).[127] 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 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[128]. 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.[129]

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 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 a foothold on the American defense market by providing maritime patrol planes for the coast guard[130].

8.3.2 Interruption in an emergent innovation system

The industry lost 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 the global competitive landscape. The Indonesian strategy of self-reliance was diametrically opposite to the alliance-favoring trends the global aircraft industry was transiting to already 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 the 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 to continue to grow.

In this setting the aircraft industry was unprepared to face the East Asian financial crisis and to lose its only financial resource. The attempt to raise "private" capital through the DSTP project and the efforts to find foreign investors 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

[127] "Toughing it out" *Flight International*, 25-31 Jul 2000
[128] *Flight International* 28 Oct 2008
[129] "PT DI makes components for France's Eurocopter" *The Jakarta Post* 28 Jan 2010
[130] "EADS-CASA all at sea" *Interavia*, Summer 2006

a still stand. The effect of the interruption was hardly as devastating in any other country as it was in the case of Indonesia:

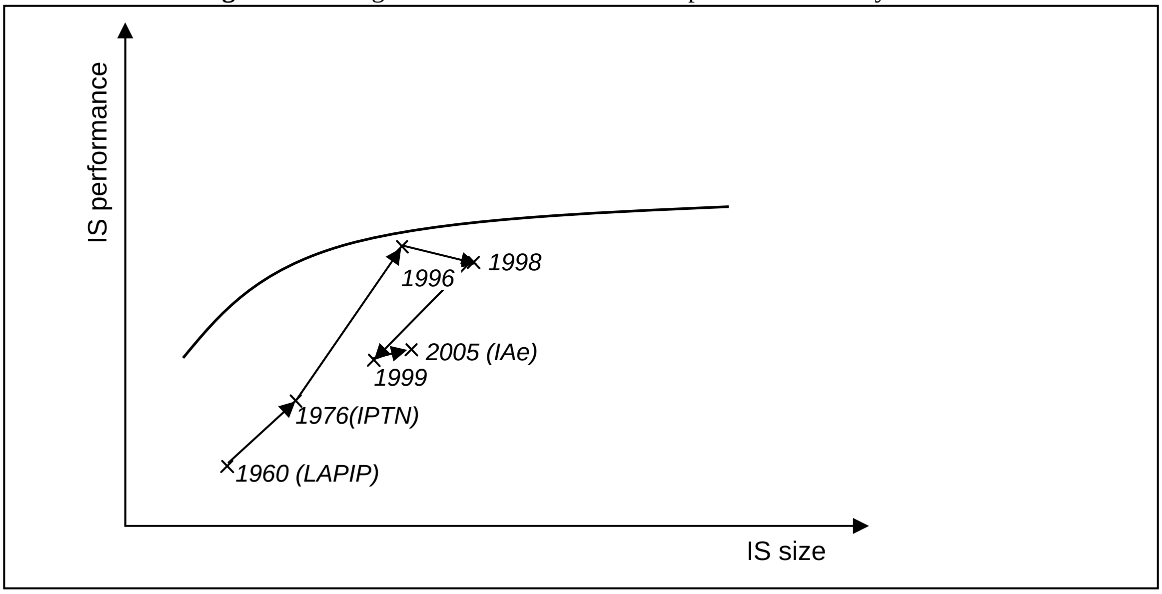
- Reduction in the capital flows. In accordance with the agreement with the IMF, all government support to IPTN was cut, leaving the company virtually without any source of finance. Part of the equipment and machinery in research institutes was also dismantled and sold abroad.
- Reduction of human capital inflow. 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, while the program was given a more general profile. Many of the staff were forced to take a sabbatical years abroad, a number of experts left to Malaysia or the Netherlands.
- Halt of innovative activities. As a result of lack of funding, IPTN shelved the N-2130 project and the certification of the N-250.
- Production output. Apart from the planes already in an advanced stage on the production line, the factory came to a halt.
- 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 it could not exceed 37 million in 2005.

8.4 *Conclusion*

8.4.1 Emergence and interruption

Based on the findings in section 8.3, Figure 27 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.

Figure 27 Emergence of the Indonesian aerospace innovation system



Source: The authors

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 7). 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 8). 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.

8.4.2 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.

Coping with this uncertainty and overcoming the lack of infrastructure, human and physical capital, were theoretically sound arguments for government intervention.

Indeed, there was a congenial political environment during the whole development of the industry right until the crisis (McKendrick, 1992). Many comparable policies were applied by Western and emerging country government 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. The problem with the strategy was that it was a technology push strategy. It gave too much priority to technology development over financial and marketing considerations (Goldstein, 2002). In particular it was not compatible with the changing global competitive environment. However, there is ample evidence that both at the company and at government level Indonesia made serious attempts to sell IPTN's planes and to take market demand into consideration. It is essential to prove the company's technological know-how in order to attract private investors, which, to a certain degree, justifies Habibie's obsessions. Yet, 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. A possible strategy to realize a transition to more sustained competitiveness would had started with the identification of the desired core competences of Indonesian Aerospace. This might not have been the manufacturing of complete aircraft, but rather the production of parts and components, with which the company could have participated in global supply chains.

In order to secure new sources of capital sources IAe will need to convince investors of its existing and future capabilities. The fact that these are still underdeveloped, especially given the technological advances of the industry leaders, calls for a major role of the government in supporting the potential creation of a new innovation system. The government's role should however not only focus on financing productive activities, but also providing a flow of highly trained, highly skilled labor and access to technology and markets.

Excessive government attention for aerospace in a developing country has had the unintended consequence of shifting much needed resources (including policy focus) from other promising sectors. A look at Indonesia's industrial development in a broader context justifies these fears. According figures presented by Hill (1990), the disproportionately high levels of protection for engineering and metal manufacturing industries received were not justified by the growth of their relative size in Indonesia. We do see aircraft manufacturing value added increase between 1975 and 986 from almost nothing to 22 million USD, which exceeded the average industrial 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 (Table 11).

Aerospace manufacturing may have been too big a jump for Indonesia. The industry was established as an island of high-tech in a sea of low-tech. 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 Paolo or Rio de Janeiro hade 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 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 significant manufacturing capabilities in a remarkably short period of time, but has remained commercially weak. Securing foreign sales is paramount to decreased 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 any crisis. Even without the Asian crisis, innovation was not sustainable in the system. Since 1998, it continues to decay.

Table 11 Value added in East Asian and the Brazilian Aerospace industries (1990-2005)
(Million USD at constant = 2000 prices)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2005**
China (P.R.)	2,402	1,758	1,775	1,692	1,692	1,587	1,445	1,951	1,795	1,950	2,297	2,787	5,098
Indonesia	48	75	167	192	46	206	433	177	24	4	227	191	37
Japan	1,642	1,786	1,979	2,235	2,145	2,272	2,217	2,261	2,796	2,851	2,449	3,031	2,985
South Korea	216	263	109	144	283	216	202	236	262	297	487	536	523
Malaysia	38	32	37	35	34	43	37	47	39	49	71	59	128
Singapore	403	403	575	638	653	673	732	974	854	1,004	1,034	1,364	1,880
Brazil	630	442	338	260	166	278	357	641	845	1,855	2,348	3,556	1,783

Source: UNIDO; CNBS; GGDC 60-Ind.; IBGE
Note: PPPs from GGDC (updated to 2000) applied are 4.6 CNY/USD; 4201.2 IDR/USD; 125.2 JPY/USD; 905.9 KRW/USD; for Brazil 1.09 BRL/USD applied; PPPs from World Development Indicators applied: 1.68 MYR/USD and 1.19 SGD/USD

9 Conclusion and Discussion

In section 4.9, we formulated three questions which served as a guideline for the case studies. 1. What trajectories did the latecomers in aerospace follow? 2 What caused the interruptions in the development of the sectoral innovation system? and 3. What were the characteristics of the transition period? Here we summarise our findings and conclusions under the same headings.

9.1 *Latecomer trajectories*

Trajectories of latecomer industrialization in aerospace followed a pattern of interrupted innovation. Countries narrowing the technology gaps with the lead countries did not simply accumulate capabilities in an incremental fashion as suggested by stage theories of catch up. 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 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: 11). But it has remained less articulate about the actual patterns of co-evolution. The conclusion of this paper is that 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 crises and transitions. The cyclical changes in the performance of the sectoral innovation systems are closely interconnected with cyclical swings in value added in the industry.

Measuring innovation system performance in an unambiguous manner turns out to be difficult, as the changes in performance are too complex to be captured in a single composite indicator. 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 can also be used to identify interruptions in the innovation system. All indicators are very context-specific, and the identification of historical turning points requires both quantitative data and in-depth qualitative studies of institutional and organizational changes in the industry.

It is important to be able to predict crisis and transition periods. Archibugi *et al* (1999) criticize the Galli and Teubal model (1997) for its lack of predictive capacity and the lack of evolutionary elements in it. We argue that a careful selection of indicators can reveal structural problems in a sectoral innovation system. We assume that major incumbent actors and potential new entrants can also read these signals. However, this does not necessarily mean that change will actually take place.

The length of periods of growth between interruptions varies from country to country, although the increased internationalization of production and consumption has resulted in increasing overlaps between the country experiences. The end of the Cold War caused a major crisis in the global aerospace industry and countries that entered the industry at different times and had acquired different levels of capabilities, all experienced a crisis during the mid-1990s.[131] But in Argentina, Brazil and China major interruptions had already occurred well before the end of the Cold War. This indicates that country-specific factors matter at least as much as industry-specific ones.

Country-specific factors appear to matter similarly 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). The longer the period, the less flexible an innovation system is to adjust, using the terminology of McKelvey et al (2006).

In this paper we have distinguished two phases in the 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 necessarily associated with an interruption (section 4.9, question 1.b). 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, before the crisis and interruption around 1990. Nevertheless, a transition provides 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 funds were indispensable for the emergence of an innovation system.[132] In Brazil CTA and ITA were funded by the government and so was Embraer at the time of its establishment. Private capital was not 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 becomes 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. The question is whether it could have been managed more smoothly.

[131] And experience one even more simultaneously during 2008-09, although this remains beyond the scope of this paper.

[132] 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.

9.2 *Causes of interruptions*

The framework of interrupted innovation focuses on the evolution of innovation systems and not on technological change alone. Evidence from the case studies showed that innovation system changes were not triggered by internal factors, such as a slowdown of innovation dynamism as the innovation system comes close to its innovation performance frontier, or domestic innovation at the frontier. Instead, *exogenous system shocks* play a crucial role in interruptions. This is due to the latecomer setting and the capital- and technology intensity of the aerospace industry, Outside shocks, either in the form of falling sales revenues or the drying up of available public funding, can result in the depletion of resources available for innovation and the inability of the industry to respond to competitive challenges.

With regard to external shocks, we conclude that first, radically new technologies need not originate from within a latecomer industry to revolutionize the industrial structure. None of the four countries we examined introduced technologies that made leading producers' technologies obsolete. On the contrary, changes in the production structure (the increased use of hierarchical global supply chains by American and European producers) triggered changes in Brazil and China. Thus, Embraer endorsed the risk sharing partnership model and China shifted track to become a major component supplier. Second, even if technological change in the leading countries plays a role in radical institutional change in emerging producer countries, these changes are more likely to be triggered by economic and political events external to the industry. This is due to the fact that during the emergent phase the industry relies heavily on government support as both investor and customer. Third, key players are rarely replaced. Major incumbent aerospace manufacturers in emerging economies are very likely to survive interruption, transition and subsequent consolidation periods. This may be a particularity of the industry, where huge sunk costs and power relations provide sufficient incentives not to let national champions go under.

We conclude that the causes of interruptions were almost always exogenous to the sectoral innovation system, rather than endogenous. The financial crises and the fall of the military regimes in Brazil and Argentina, the economy-wide changes of introducing market-mechanisms in China or the Asian financial crisis in 1997 were all external to the industry.

9.3 *Characteristics of sectoral innovation system transitions*

Common features of transition

There are surprisingly many common features in successful 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 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. In the following paragraphs, we address four subquestions with regard to the characteristics of innovation system transitions (see section 4.9).

a. How did interruptions and transitions affect the accumulation of technological capabilities?

Every time an innovation system changes, the competitive challenges change as well. This requires innovating actors to develop different technological capabilities. It depends on the nature of transition how much of the capabilities acquired in earlier growth periods, can be applied in the following one. If the mismatch between already acquired capabilities and the requirements of the new competitive landscape is too great, this prolongs the period of transition. This could be clearly observed in China in the 1990s. On the other hand, much of the existing capabilities of the Brazilian innovation system could be applied after 1994 as well. The role of educational institutes and R&D labs are undoubtedly important in the transition process.

b. Who were the actors governing the transition period?

The competitiveness of the industry during the subsequent growth period depends largely on which actors play the leading role during the formative and transition periods. Especially during the emergence phase, the government is indispensable. 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, performed more successfully. The comparison of Argentina and Brazil in terms of governance is very telling. In both countries the military played a crucial part in the establishment of aerospace research and production activities. But the success of Brazil already in the 1970s 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.

c. 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 a system survives an interruption can 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.

Successful Transition – with coordinated intervention

Transition processes are uncertain and changing established routines and laws is costly. However, if an interruption occurs, the cost of “non-transition” increases rapidly. There are negative external effects, due to growing unemployment, loss of expertise that cannot 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 mandate to try to initiate systemic change. But firms and entrepreneurs also have an important role given the competitive challenge the industry faces.

Both the emergent and the transition phases require coordinated action by the key stakeholders, involving the identification and creation of missing institutions. Transition will not occur unless there is sufficient will. 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.

Failure of transition: interruption during the emergent phase

The timing of interruption is one of the important factors explaining the success or failure of transitions. We identified an *emergent or formative phase* at the beginning 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 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).

In section 3.1 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, 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 sufficient 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 sufficiently matured 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 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 redefining 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 redefining 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 foreign investment. The more developed an innovation system is, the higher its chances to acquire new sources of capital. The cost of entering the aerospace industry as a latecomer entails the cost of establishment of an innovation system.

d. Transition institutions

The role 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.

If national security considerations are more important than commercial ones, the chances are high that the institutions created during the transition will not be conducive to sustainable growth. This is clearly a lesson from Argentina, but also from the early decades of industry development in China.

9.4 *Further research*

In the development of aerospace, the importance of institutions[133], capital, skilled labor and strategic considerations is probably greater than in other industries. It is an interesting question for further research whether the framework of interrupted innovation developed in this paper is also applicable to other industries. Latecomer sectors that combine high technological and capital entry barriers, distorted markets and a high regulatory role of the state (such as other transport equipment industries, some specialized segments of electronics (e.g. medical instruments) or energy production) are sectors where this framework might well be fruitfully applied. But it is also interesting to examine whether the framework is applicable in low-tech industries.

[133] See e.g. Texier (2000)

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