11195

INDUSTRY AND ENERGY DEPARTMENT WORKING PAPER
INDUSTRY SERIES PAPER No. 58

Learning, Technical Progress and Competitiveness in The Commuter Aircraft Industry: An Analysis of Embraer

June 1992

The World Bank Industry and Energy Department, OSP

LEARNING, TECHNICAL PROGRESS AND COMPETITIVENESS IN THE COMMUTER AIRCRAFT INDUSTRY:
An Analysis of Embraer

Claudio R. Frischtak
Consultant
Industry Development Division
The World Bank

June 15, 1992

The World Bank does not accept responsibility for the views expressed herein which are those of the author and should not be attributed to the World Bank and its affiliate organizations. The findings, interpretations and conclusions do not represent official policy of the Bank. The author is grateful for the thoughtful comments of Peter Scherer and Carl Dahlman, the excellent research assistance of Basanta Chauduhri and Solange Pires, and Embraer for the detailed information provided.

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

1.01 The objective of this paper is to present an analysis of the international commuter aircraft industry. The focus is on the difficulties faced by industrializing country firms to enter and consolidate their position in a highly competitive market in a complex product area. The case of Embraer, one of the few and the most prominent aircraft manufacturer in the industrializing world, is illustrative in this regard. Embraer started operations in 1969. A relatively young firm by the industry standards, it experienced a period of accelerated growth for two decades before petering out after 1989. A combination of recessionary forces in the commuter airline industry and the military aircraft market, intensifying competition from better financed firms, and an overambitious development program, have led to substantial losses in 1990 and 1991. In early 1992 the Government decided to privatize Embraer in view of the company's high level of indebtness and the Government's unwillingness to come to its rescue with a package that would effectively restructure its balance sheet.

1.02 The case of Embraer has been the object of other papers. For the most part, they have discussed Embraer's early efforts with the Bandeirante, a 19-passenger commuterliner and the company's mainstay product in its first decade.[1/] This paper is basically concerned with the last ten or so years of Embraer in the broader context of a rapidly changing commuter aircraft industry. For Embraer, this period has been characterized by significant technological achievements--the co-development of the AMX fighter jet and of the CBA 123 pusher prop--and commercial successes. This has been also a period of growing financial difficulties, partly an outcome of a number of bold, and, in retrospect, wrong decisions concerning product development strategy and financing.

1.03 The next chapter describes succinctly Embraer's history and the evolution of its product line. It shows a state enterprise that became surprisingly successful few years after start-up with the Bandeirante commuterliner. Certified in and exported to a number of major developed country markets, the Bandeirante was followed by other products catering both the civilian and military markets. Two succeeded in establishing a strong competitive position in their respective segments: the 30-passenger Brasilia commuter turboprop and the Tucano military trainer. Yet product development go-ahead decisions undertaken in the mid to late 1980s regarding the CBA 123 and Embraer's new regional jet did not fully take into account less expensive alternatives nor the financial restrictions Embraer faced, and brought the firm to an unsustainable financial position.

1.04 Chapter III discusses Embraer's technology strategy and performance. There is little doubt that the Bandeirante and the products that

---

1/ See, for example, R. Ramamurti, State-Owned Enterprises in High Technology Industries -- Studies in Brazil and India, Praeger, New York, 1987, Chapter 5; Ravi Sarathy, "High-Technology Exports from Newly Industrializing Countries: The Brazilian Commuter Aircraft Industry," in California Management Review, n.2, Winter 1985, pp. 60-84; and D. Mowery, Alliance Politics and Economics -- Multinational Joint Ventures in Commercial Aircraft, Ballinger, Cambridge, 1987, pp. 114-120.

followed it were the outcome of determined efforts in design and systems integration. Equally important were the systematic steps undertaken to acquire manufacturing capabilities and critical skills through licensing, subcontracting and co-production agreements, and the experience accumulated over time, as output expanded. Technological performance indicators show substantial improvements over time; in a number of instances, they conform to frontier parameters, as for the Brasilia's learning curves. Despite Embraer's technological achievements, the firm in retrospect made significant mistakes. The costly development of an "overdesigned" commuterliner--the CBA 123--and a commitment to the "prestige" of a regional jet (the EMB 145), have become major obstacles to Embraer's survival. These errors of assessment reveal, from a strategic stand-point, an overemphasis on the performance side of the price-performance equation, and a tendency to respond with "engineer-driven" solutions to market requirements.

1.05 Chapter IV notes two opposing but closely related trends in the international commuter aircraft market: growing rivalry and cooperation. The international commuter aircraft market has undergone a major transformation in the last 20 years--from one with relatively few producers, manufacturing models of older design, and not very demanding clients, to a market where competition is intense in price, financing terms, aircraft overall performance and componentry. Starting in the mid 1980s, a number of aircraft producers began facing losses, despite their relatively good products, trim workforces, and strong technological and marketing capabilities. Included among them were de Havilland, Fairchild, Fokker, SAAB, Shorts, British Aerospace and others. The prospects for this decade is one of growing rivalry; many actors will have to exit or be content with a smaller role.

1.06 When Embraer introduced the Bandeirante in the U.S. market in the 1970s, the response of rivals was limited. Beech and Fairchild did not have the products or the finance to compete effectively. Fairchild, on the other hand, attempeted unsuccessfully to have the U.S. government impose duties (denied in 1982 by the U.S. International Trade Commission--ITC). As a result, the Bandeirante reached a 20% U.S. market share in the early 1980s before its position started to erode due to entry of new competitors. Embraer followed the Bandeirante with a larger aircraft, the Brasilia. Launched in 1985, the Brasilia attained approximately 35% of the U.S. market share within five years. Yet competition in all market segment intensified by the late mid to late 1980s, with new or upgraded products entering the market aggressively. Firms to maintain their position were obliged to sacrifice profit margins, which have been historically small. Embraer's "easy ride" in the U.S. (and, to a lesser extent, in the European) market was over, and by 1990 it also saw major losses.

1.07 The first important observation is that firms with excellent manufacturing capabilities and production records, such as Embraer and others, are facing substantial difficulties. The fundamental reason is that while the market became more crowded in the 1980s, making it increasingly difficult to pursue a niche-oriented strategy, development costs escalated as well. They currently range from US$ 250-650 million per new model. In view of the impact of cumulative output on unit costs, new model sales have to be very substantial before they break even; as development costs rise and competition intensifies, this threshold moves up. Profitability becomes a possibility only further into the future. Any attempt to recoup development costs in the short to medium-term runs the risk of pricing the product out of the market.

1.08 Moreover, it is not enough to have one good product and to know how to manufacture it well; this is a necessary condition. Increasingly firms need to offer customers a family of products, with enough continuity and "communality" to supply its differentiated needs on a least-cost basis. Just as one finds economies of scope in design and production, there are such economies in use. Yet, to be able to offer a family of aircraft to supply the needs of commuter airlines is obviously very demanding of the firm's finances. Those that decided to do it alone, carrying on a number of projects simultaneously, need very "deep pockets," even when they employ cost-minimizing strategies such as designing within the "family" and upgrading existing models. Although firms have often resorted to government subsidies, governments have generally been unwilling to cover losses indefinitely. Thus the attempt by producers to find partners, establish risk-sharing alliances, downsize operations, or exit altogether through sale of assets or some other means.

1.09 Chapter V of this paper concludes by drawing the implications of Embraer's experience for industrializing countries. Embraer's predicament is not unique and reveals the problems facing industrializing country firms in areas that have normally been the realm of developed country producers. Embraer was able to successfully exploit a niche in the market in the mid 1970s with the Bandeirante, followed by two well-accepted products: the Tucano and the Brasilia. Yet remaining at the forefront in an area of complex technology, at a time of intensifying competition, growing development costs and risks, requires both substantial financial resources and solutions (designs) of new projects that are strictly market driven. On both counts, Embraer has lagged with the EMB 123 and 145, and both programs were by end 1991 put on hold.

1.10 As in a number of other complex and technologically demanding industries, to compete effectively as a "loner" in the aircraft industry is becoming increasingly difficult. Even for those firms that enjoyed early successes and are quite capable from a technological standpoint, survival will depend on flexible and creative strategies--co-development arrangements (with suppliers' finance, for example), co-production agreements, and introduction of "complementary lines." Even such strategies, however well designed, may not be enough to guarantee survival, as the market absorbs new products in the 1990s, development costs rise, and the price-performance frontier moves out.

1.11 Some countries might opt for subsidizing heavily the industry (or a single "national champion") in view of the fact that other countries transfer subsidized resources directly or indirectly, and on the presumption that the aircraft industry provides significant externalities. What would be those externalities and how to capture them to the benefit of the country? Training effects, the development of subcontracting arrangements, and the formation of growth poles constituted of firms in technologically sophisticated areas are the prime examples of spillovers that might be associated with the industry.

1.12 Yet such externalities would have to be very substantial and be present for a long period to justify Government support. Rough estimates suggest that most commuter aircraft producers have cost governments US$ 1-2 billion directly and indirectly. It is unlikely that the spillover benefits of an aircraft industry (or the prestige associated with it) compensates for transfers of such a magnitude, particularly in countries where the opportunity cost of capital (and therefore the rate of return from alternative projects) is high. The industry does not appear to be a particularly appropriate or effective development instrument.

1.13 First, associated training effects and other learning externalities, though occasionally important, could hardly justify the outlays involved in guaranteeing its survival. If one estimates that it costs some US$ 200,000 to train a competent researcher, a US$ 1 billion allocation (assuming a 7% rate of return) would pay for a yearly addition of 350 scientists and engineers to the country's stock of highly qualified personnel, or five times as many skilled workers (on the presumption that training such worker would cost up to US$ 40,000). Moreover, training effects can only be considered externalities if labor is eventually released from the activity and is employed making full use of learned skills in the country. Aircraft design and fabrication, however, demand sufficiently specialized skills that, in smaller economies, where aircraft production is the monopoly of a single firm, alternative sources of employment are unlikely to make efficient use of skills learned.

1.14 Moreover, the labor requirements of an aircraft industry are such that in countries where the engineering and scientific base is thin, these activities may absorb a disproportionate amount of such scarce resources, and crowd out other economically relevant activities. Have the social returns from aircraft design, components production and systems integration, justified the allocation of such resources, particularly in countries that have both scarcity of capital and skilled manpower? It would be difficult to argue so.

1.15 The externality-grounded rationale that is more appealing is one even harder to quantify. It is related to the potential "spin-offs" of aircraft production, including the development of a multitude of component suppliers and subcontractors, and the creation of an industrial culture of exacting standards and tight quality control, that when combined would bring the creation of a regional growth pole. However, investments in social and physical infrastructure (such as high-level educational institutions, industrial research parks and a telecommunications network) are more likely to lead to the development of "high-technology" growth poles. If, therefore, there are few externality grounds (other than possibly national prestige) to subsidize aircraft producers, then their survival should fundamentally depend on the ability to maximize value and generate profits. Increasingly governments may be looking for producers to either become self-sufficient entities, or associate with other firms, or exit.

II. A BRIEF HISTORY OF EMBRAER

2.01 Although the production of airplanes in Brazil dates back to 1910, when the first monoplane was built in the country, the development of the Brazilian passenger aircraft industry can be equated with the development of Embraer.[2] The creation of Embraer in 1969 was the culmination of a process which started almost thirty years earlier, when a new Ministry of Aeronautics was established in 1941, attached to which were directorates of education and technology (as they were then called). The Ministry was to provide strong material and political support for training and research in aeronautical sciences with creation soon after of the School of Aeronautics Engineering, transformed in 1946 into the Instituto Tecnologico da Aeronautica (ITA). ITA was inspired by the MIT model and in fact, a number of professors from the Aeronautics department of MIT (as well as German engineers) went to work at ITA in the early years. By 1988 ITA had trained more than 3000 engineers, 800 of which were in the aeronautics field[3].

2.02 In 1950, the Centro Tecnico de Aeronautica (CTA--today the Centro Tecnico Aeroespacial) was created as a teaching and research center, and staffed with engineers trained by ITA, which also became part of CTA.[4] In 1965, the Center undertook a major project: to build an aircraft to replace the Air Force's aging DC-3s. Under the guidance of a well-known french designer, a team of Brazilian engineers developed and tested a prototype. The Bandeirante turboprop had its first successful flight in 1968. The original team that had designed the Bandeirante (the name given to the aircraft) was then transferred from CTA to Embraer, which was created in 1969 with the purpose of producing the Bandeirante on an industrial scale, based on

---

2/ There have been other important local aircraft producers. The Compania Aeronautica Paulista, founded in 1942 by Francisco Pignatari, produced 700 monoplanes. The Compania Nacional Construtora Aeronautica Neiva manufactured more than 500 planes of its own design between 1959 and 1975, including a trainer which was exported to Chile. Aerotec, founded in 1962, produced another monoplane trainer for the Air Force.

3/ The ITA/CTA graduate engineering education/research nexus was instrumental in the development of Brazil's first and largest technology park around Sao Jose dos Campos. Along with Embraer, CTA has led to the establishment of a number of high technology companies including: Avibras (missiles), Orbita (missiles), Engesa (military equipment), Tecnasa (electronic communication equipment), Composite Tecnologica (composite materials), and Quantum (software).

4/ The CTA consists of four institutes: ITA; the Institute of Research and Development (IPD), which does R & D in aeronautical engineering, electronics, new materials and mechanics; the Institute of Space Activities (IAE), which focuses on space-related activities; and the Institute of Development and Industrial Coordination (IFI), which is in charge of coordinating and supporting activities to consolidate and develop the aerospace industry in Brazil. CTA has been active as well in the energy-substitution program, particularly the certification of alcohol engines and the search for a diesel fuel substitute.

a 80-unit launch order from the Air Force. The plane was eventually a commercial success and found a niche in the international commuter aircraft market; the aircraft also played a fundamental role in establishing Embraer as a world-class manufacturer of regional aircraft.

2.03 Embraer's product line consisted at the end 1991 of 3 major airplane models of own design in current production: the Brasilia commuter aircraft, the Tucano military trainer, and the AMX subsonic fighter jet (co-designed and co-produced with Italian firms). Embraer has at the prototype stage the CBA-123 (Vector), a 19-passenger aircraft to substitute the Bandeirante, and a stretch jet-powered version of the Brasilia in development. Under license from Piper, Embraer produces 3 models of small general aviation airplanes in its subsidiary Industria Aeronatica Neiva (where it also manufactures the Ipanema agricultural spray plane). In addition to the Bandeirante, whose production stopped when approaching the 500th aircraft, Embraer has phased out the Xavantes, a bomber produced under license, and the Xingu, a pressurized twin engine 9-passenger turboprop. Embraer's accumulated production at the end of 1989 stood at 4189 aircraft, including 2240 of Piper line, and 135 Tucano kits shipped to Egypt. A detailed description of Embraer's product history follows (see Table 1 for a listing of Embraer's products since its inception).

Table 1: EMBRAER'S AIRCRAFTS 1969-1992

Production name	Type	Production dates a/
Bandeirante -- EMB 110/111	Commuter aircraft 19-passenger turboprop with military versions	1972 -- 1989
Xavante -- EMB 326 GB	Military trainer light bomber jet	1971 -- 1981
Ipanema -- EMB 200/200A, 201/201A	Agricultural spray plane	1982 --
Piper Line	General aviation	1975 --
Xingu -- EMB 121	Executive aircraft	1979 -- 1987
Tucano -- EMB 312	Light military trainer turboprop	1980 --
Brasilia -- EMB 120	Commuter aircraft 30-passenger turbo	1985 --
AMX	Fighter -- Bomber subsonic jet	1989 --
Vector -- CBA 123	Commuter aircraft 19-passenger turbo	Prototype stage
EMB - 145	Commuter aircraft 45-passenger jet	Under development

a/ The dates refer to serial production start-up and phase out.

2.04 Embraer started out with 3 quite distinct projects: the Bandeirante, the Xavante and the Ipanema. The Xavante (EMB 326 GB) was a twin seater pressurized jet trainer and ground attack plane whose manufacture was started in 1971 through a licensing agreement with Italy's Aermacchi.[5] By 1981, when this aicraft was phased out, Embraer had produced 182 units, with 16 exported to the Uruguayan and Togo Air Forces (10 and 6 respectively). The importance of the Xavante project to Embraer was related to the transfer of manufacturing technology from the Italian parties (see chapter III), and the inflow of resources propitiated by the Air Force order. The Ipanema (originally EMB-200), on the other hand, was a project targeting a preexistent civilian market niche--of light agricultural planes for farmers and private sprayers--with an aircraft designed at the CTA. Just as with the Bandeirante, the Ipanema project was transferred to Embraer to help it diversify its product line and fulfill a perceived market need. The first prototype flew in 1970, and three improved versions (in the sense of more payload, power, and better overall performance) were introduced between 1972 and 1976 (the EMB-200A, 201 and 201A). The aircraft is a single seater powered by a 350HP engine, able to carry up to 680 liters of chemicals and is used for seeding, fertilizing, and spraying. 640 Ipanemas were delivered by end November 1991, with just 13 exported to Latin America.

2.05 Of the three original projects at Embraer's inception, it was the Bandeirante (EMB-110/111) by far the most important. The Bandeirante was developed originally for the Brazilian Air Force (Forca Aerea Brasileira--FAB), at the Institute of Research and Development of CTA. In the early sixties, FAB was worried that the old stock of DC3s, which formed the backbone of air travel to hundreds of small airports in the interior of the country, were wearing out, and that there was no product that could replace them in the advanced segment of the market. The technological frontier was moving increasingly toward larger jets, which could not operate on the short and often unpaved runways characteristic of airports in the interior of Brazil, whereas in the small general aviation segment the planes were too small.

2.06 As a result, in 1965 FAB commissioned CTA to design a plane smaller and faster than a DC3, but larger than the small four-seaters which were then available in the general aviation class. Since the idea was to produce the plane locally, it was also decided that the new plane should be a turbo-prop rather than a jet, because the latter was too ambitious a goal. Initially there was much skepticism that an airplane of that complexity could be designed locally. The presence of Max Holste, a well known French design engineer to formally head the project (and which had designed in France the Nord 260, a small twin turboprop), no doubt contributed to its completion within a 3-year time frame[6]. In 1968, the first prototype of the Bandeirante flew successfully.

5/ The plane is also produced under license in South Africa (as the Impala) and in Australia.

6/ See R. Ramamurti, op.cit., pp. 184-5.

2.07 The Bandeirante model which became the dominant version is a 19 passenger aircraft, designed for short-haul feeder line passenger transport. Military transport, air drop, SAR (search-and-rescue), ambulance, aerial photogrammetric and remote sensing versions were other derivatives of the same airframe.[7] Yet it is the passenger civilian version of the Bandeirante which was most successful--of the 491 units comprising all Bandeirante versions that were delivered since 1973 (and up to end November 1991), two-thirds operate in more than 45 regional airlines in 36 countries.[8] During the period 1969-80, out of 324 Bandeirantes produced, 143 were sold to foreign airlines (44.1%), 105 to the Brazilian and other Air Forces and 76 to domestic operators (23.5%). During 1981-85, 135 additional Bandeirantes were produced, with most exported to foreign commuter airlines; after 1985, the rate of production decreased substantially and 32 more were manufactured, after which production ceased.

2.08 Certified in Brazil in 1972 and first delivered to the Air Force in 1973, the Bandeirante initial sales in the international market were to Uruguay (1975), and two years later, to France, England and Australia.Although the 1977 sales to British companies (Air Wales, CSE Aviation, Fairflight) represented a major achievement for a relatively young company with a still unproven product, Embraer's efforts were directed in significant ways to the U.S. market, which at that time represented 50% of the world market for commuter aircraft. Embraer entered the U.S. market in 1978, with the Bandeirante mixed passenger-cargo transport version (110-P1). Soon after the aircraft was FAA certified, and still during the same year (1978), Embraer delivered the first all-passenger Bandeirante to a U.S. operator (Wyoming Airlines). In the period 1979-82, the U.S. market for 15-19 passenger aircraft averaged 73 units; Bandeirante's share was 31.6% of the total and 61.3% of the imports.[9] The U.S. became eventually Bandeirante's most important export market (of the 481 EMB-110 delivered, 130 operate in the U.S.).

2.09 The EMB-110 success is explained first, by its reliability and relative sturdiness (consistent with its original objective of serving as a

---

7/ A total of 11 models of the Bandeirante were introduced between 1972 and 1978: the EMB-110, a 12-passenger military liaison transport (1972); the 110C, a 15-passenger for local airlines (1973); the 110E/J, a 7-8 passenger executive transport (1975); the 110P, an 18-passenger feeder liner (1975); the 110S1, a 2-passenger geophysical survey plane for the Air Force (1976); the 110B1, a convertible 14 passenger and aerial photography aircraft catering private operators (1976); the 110B, a 5-passenger aerial photogrammetric aircraft (1977); the 110K1, a cargo-paratrooper (1977); the 110P2, an 18-19 passenger commuter liner for foreign airlines (1977); the EMB-111, a maritime patrol aircraft for the Air Force (1977); and the 110P1, a mixed passenger-cargo transport for foreign airlines (1978). Data taken from R. Ramamurti, op.cit., Table 5.1, pp. 178-9.

8/ In addition, 31 units of the maritime surveillance version of the Bandeirante (EMB-111) are in operation in Brazil, Chile and Gabon.

9/ Calculated from Table 3 of R. Sarathy, op.cit., p. 64.

military transport), combined with a moderate price.[10] The Bandeirante was designed to operate from short, unprepared or unpaved strips, and with minimum ground support. In fact, one of its attractive characteristics has been the ability to remain operational in extreme conditions (for example, runways covered by mud, dust or ice). The EMB-110 became known to operators as a very rugged aircraft, requiring low maintenance, and offering short turnaround times, high dispatchability and cargo-passenger versatility.[11] Among its disadvantages were the shorter range and higher fuel consumption (27%-36%) than its major competitors at the time (Beech's C99, Fairchild's Metro III and De Havilland Twin Otter). In part, this was compensated by a competitive price (the price per seat for the Bandeirante was US$ 94,000, compared to US$ 121,000 for the Metro III and US$ 86,666 for the C99--data on the Twin Otter was unavailable), a 45-day delivery time, and better financing terms (basically lower interest rates--9% vs. 15%-18% for U.S. aircraft). Although it was argued at the 1982 ITC hearings that export financing terms constituted a decisive competitive factor in favor of the Bandeirante--the ITC estimated that the price impact from the interest rate differential was between 9% and 20%--it is unlikely that a product with significantly weaker performance characteristics than the Bandeirante would be a commercial success, as evidenced from the slow growth in market penetration of aircraft from other countries which counted with similar financial arrangements.[12]

2.10 The Bandeirante success in the U.S. market was also related to the timing of entry. With the 1973 oil crisis, the cost of jet fuel soared, leading to a reduction in services and fewer nonstop fights. Passenger air transport deregulation led large operators to phase out from smaller or less dense markets, which were unprofitable to operate with their fleet configuration.[13] A small turbo-prop in the 15-19 passenger category, the Bandeirante

---

10/ See the excellent comparative analysis of the performance characteristics of the Bandeirante and its competitors in the American market in R. Sarathy, op.cit.

11/ In the ITC 1982 hearings on the unfair trade practice complaint filed against Embraer by Fairchild, operators praised the aircraft for its workhorse type characteristics and better established and reliable engines. The latter seemed to have played an important role due to the problems found with Garrett's powerplant that equipped Fairchild's Metro III. See R. Sarathy, op.cit., pp. 68-9.

12/ In the 1980-81 period, for example, the numbers of Bandeirante in operation grew by 140% -- from 27 to 65; Canada's De Havilland Twin Otter expanded by only 5 -- from 97 to 102, a 5.2% increase; and Australia's Government Aircraft Factories Nomad climbed by just 2 units, from 5 to 7. Data taken from Table 2, R. Sarathy, op.cit., p. 63.

13/ "The Airline Deregulation Act of 1978 changed airline industry structure to the benefit of commuter airlines. The act gave large carriers freedom to market entry and exit; as a result, they withdrew from smaller, short-haul markets. About 100 cities lost all jet service, with 170 smaller cities in all losing some jet service. This left commuter airlines with some monopoly in several markets. CAB certification became easier to obtain, and joint fare agreements between commuters and large airlines were encouraged...As a result of the Act, 1979 became the best year in commuter airline industry." See R. Sarathy, op.cit., p. 60.

found a niche in short commuter runs (less than 300 miles), where its operational costs were much lower than jets'. Demand for small commuter aircraft expanded substantially in what was then and has remained since the largest market in the world for commuterliners, and at a time when this niche was occupied by only three other models: Fairchild's Metro III, Beech's C99 and De Havilland's Twin Otter. In fact. the Metro was the only aircraft in the 15-19 passenger category being manufactured in the U.S. in the late 1970s. Import competition, on the other hand, was de facto limited to Canada's Twin Otter (which had 102 units in operation in 1981). Australia's GAF Nomad was withdrawn from the market due to poor sales, while Dornier's had yet to enter.

2.11 In addition to its three core start-up projects, Embraer started in 1975 the production of the Piper Line of general aviation aircraft. A year earlier Embraer and Piper signed an agreement under which Embraer would manufacture six types of Piper aircraft. Embraer decided to enter the four to eight-seater market in 1973 in view of the fact that the Brazilian market was second only to the U.S. market for American made aircraft of that type. Between 1964 and 1974, Brazil imported 2,485 such planes, mostly from Beechcraft (10 percent of the total), Cessna (59 percent), and Piper (24 percent). Over 2300 planes were produced under this agreement by end November 1991. Currently three Piper models are produced locally (the Tupi, the Minuano and the Seneca) and three others are being assembled in Argentina as part of a joint production-marketing agreement. This category of aircraft accounted for 52.7% of Embraer's output.

2.12 While carrying out the agreement with Piper, Embraer introduced its own light executive line of aircraft, the Xingu, an eight-seat pressurized executive twin turboprop plane. Contrary to the Piper line, the Xingu was wholly designed by Embraer, and 104 were delivered. The plane was not a commercial success (due to its relatively high price), despite a strong operational record. Although marketed domestically as an executive plane, 46 were exported (41 to the French navy and 5 to the Belgian airline Sabena) to be used as a pilot trainer. With the production and sale of the last two units in 1987, the Xingu has been phased out of line.

2.13 Although the Xavante was an important experience from a technological standpoint (see Chapter III), and the Bandeirante had military versions that sold relatively well, it was the Tucano the first Embraer military project of commercial significance. A two-seat military single-engine turboprop trainer, the Tucano was originally built for the Air Force following an order of 118 units, with 50 additional options contingent on Tucano's external sales (the option would be exercised if exports were not forthcoming). During the decade of the 1980s the aircraft was one of Embraer's most successful products, surpassing even the Bandeirante in foreign sales. After signing a development contract with the Brazilian Air Force for the Tucano in December 1978, Embraer launched the Tucano in 1980, and it was first exported in 1983. By November 1991, over 600 Tucanos had been sold, and 404 delivered (including fully assembled units and kits)--118 of which to the Brazilian Air

Force. The Air Force of 12 countries operate the Tucano[14]. The weakening of the military market has curtailed Embraer's sales of the Tucano, which fell from a high of 45 units in 1987 (plus an additional 16 kits) to none in 1990 and 1991.

2.14 Embraer is currently preparing to bid for a US$ 3.4 billion 800 plane order (over a 10-year period) for the U.S. Air Force and Navy "Joint Primary Aircraft Training System" with a Tucano variant. Although the decision has been take to buy an off-the-shelf aircraft to substitute the T-34 Cessna training jets and to open bids to international competitors (in view of the poor performance of Fairchild's T-37), it has yet to be decided if it will be a jet or a turboprop (which is less costly both operationally and on a per unit basis). The latter is the trend worldwide. To attempt to succeed in this race (against an expected 21 other competitors), Embraer is testing the Tucano H since July 1991, with an engine twice as powerful as the regular Tucano, longer life and more sophisticated avionics, and with a price tag of little over US$ 3 million (against US$ 2.4 million for the regular model, the M-312). If prequalified, Embraer will possibly have to team up with a U.S. aircraft producer (most likely McDonnel Douglas, a longtime Embraer partner) in order to win the contract. In addition, Embraer is currently entertaining sales of the Tucano to Colombia and South Africa.

2.15 The other military project that has been of most significance to Embraer is the AMX. The AMX is a subsonic jet designed for battlefield interdiction, close air support and reconnaissance missions. It is equipped with fly-by-wire control, digital instrumentation, internal electronic countermeasures systems, has a small radar and infrared signature, and is powered by a single Rolls-Royce Spey turbofan engine. The AMX was developed jointly with the Italian firms Alenia (formerly Aeritalia), the project leader with 46.5% of the workload, and Aermacchi (23.8%); Embraer's share was 29.7%. This proportion applied both to development and production costs. The former are estimated to have amounted to US$ 620 million over a 10-year period (1980-89). Thus the AMX development cost Embraer (and the Air Force) little over US$ 200 million. Embraer was responsible for the design of the wings, part of the fuselage, horizontal stabilizers, pylons, fuel tanks, air intakes and landing gear.[15] 187 units have been ordered by the Italian Air Force and 79 by the Brazilian, both of single seat and two-seat aircraft. The first AMX was delivered to the Brazilian Air Force in October 1989. A number of systems are still under development, such as a flight control computer that will enable automatic deployment of maneuvering flaps and a multimode radar with

---

14/ This includes the Royal Air Force (131 Tucanos have been produced for the RAF, as well as the Air Forces of Kuwait and Kenya, by Shorts rothers of Belfast under license, after Embraer was able to outcompete, among others, the well regarded Swiss-made Pilatus PC-9 trainer, in a RAF-sponsored competition); the French Air Force (with a mid-1990 order of 80 Tucanos); and the Egyptian Air Forces (with 120 Tucanos assembled from kits in a plant near Cairo, 80 of which were then sold to Iraq).

15/ See "O Voo Alto da Embraer," in Revista Brasileira de Tecnologia, Vol. 19, No. 6, June 1988.

look-down capability (the latter jointly developed by Tecnasa Eletronica of Brazil and SMA of Italy).

2.16 With the AMX, Embraer left its traditional market niche (commuter and light trainer aircraft), in an attempt both to have a major role in supplying the Brazilian Air Force with its next generation jet, and to compete head-on with American, French and Russian (among others) newer combat aircraft in export markets. Certainly these are non-trivial objectives considering the technological discontinuities involved and the period of shrinking military budgets during which the AMX was launched. Although the Brazilian and Italian Air Forces were the launch customers, the AMX project was since its inception designed as a relatively inexpensive state-of-the-art fighter jet that would sell well in export markets outside major developed countries[16]. The intent was to build "a relatively simple, highly reliable attack aircraft at a reasonable price [able] to carry large payloads, and agile at high subsonic speeds at low altitude," a possible replacement for McDonnel-Douglass A-4 Skyhawk.[17]

2.17 In fact, the AMX is proving to be an aircraft that performs quite well (in terms of flight stability, for instance), is reliable and easy to maintain. Its main problem are the relatively low production rates mandated by declining defense budgets in Italy and Brazil. In Italy, the AMX is being assembled at a rate of two per month; in Brazil at less than one per month (four were produced in 1990, and an additional four by end November 1991). Both countries would be able to double (or more, in case of Brazil) their production rates. In mid 1991, the first two lots of AMX were under contract; most of the 72 single seaters and eight two-seaters had been delivered to the Italian Air Force. Of the 30 one-seater lot for Brazilian Air Force, 10 had been delivered (by end November 1991), though a total of 16 were produced in the period (that is since 1989). Low production rates and uncertainty regarding the last two lots of AMX have stimulated a search for export markets. Yet AMX International (the joint venture in charge of international sales) has yet to find a customer, despite a willingness to discuss co-development and co-production of the aircraft in other countries, as well as the possibility of introducing numerous modifications (new engine, radar) in the aircraft.

2.18 Three aircraft mark Embraer's recent history of passenger planes: one--the Brasilia--in serial production since 1985; another--the Vector--that remains at the prototype stage since mid 1990; and a regional jet, which is a stretch version of the Brasilia--still in the early development phase. These three aircraft epitomize both the potential of Embraer and the major problems that its management will be facing in the next few years.

16/ The aircraft actually sells for US$ 17.8 million base price -- US$ 9.8 million above the original estimate -- not including support, training or special requirements. In a recent proposed sale to Thailand (which was later canceled), the unit price was US$ 19.9 million.

17/ See "AMX Fills Air-to-Ground Role with Room for Mission Growth," in Aviation Week and Space Technology, July 15 1991, p.36 and seq.

2.19 The Brasilia (EMB-120), a 30-passenger aircraft and Embraer's main product, is an advanced twin-engine turboprop equipped with PW100-series engines designed specifically for short-haul, high-frequency operation, with low fuel consumption especially at high cruise altitudes (fuel efficiency partly being lt of low-wing design and slender fuselage). Its major performance characteristics are low operating costs and high dispatchability (due to low wing and single-point pressure refueling, and an auxiliary power unit that dispenses with ground support equipment), relatively high cruising speed (315 kt max), climb and descent rates. Embraer argues in its product literature that 30 seats is an "ideal" capacity, with the Brasilia being the lightest pressurized airliner in the 30/50 seat category, and in the upper limit for FAR Part 135 operation rules, which jointly contribute to reduce operating costs.

2.20 A mock-up of the Brasilia was presented in 1980; in July 1981, there had already been 111 orders for this new model, even though the first was not expected to fly until 1983. Deliveries started in 1985 (with 6 aircraft) and continued in 1986 with 19 aircraft, all to export markets. By December of that year, two hundred and four had been sold abroad and 25 were already in operation in the U.S. and Europe. At end 1990, Brasilia's market share in the 20-45 seat category was 25% worldwide, just slightly below that of its major competitor (the SAAB SF340). In the U.S. market, the Brasilia had the dominant position in that year in terms of the total number of aircraft in service, again for the 20-45 seat category [18]. However, the softening of the American and other markets for passenger aircraft adversely affected Brasilia's order books, as firm orders were transformed back into options or canceled (Table 2).

Table 2: BRASILIA'S ORDER BOOKS POSITION

	End 1989	November 1991
Firm orders	275	73
Options	151	171
Total	426	214
Deliveries	160	235

Source: Embraer.

2.21 The CBA-123 (Vector) is a high performance 19-seat pressurized plane for regional airlines and corporate transport, with aft-mounted pusher

18/ Brasilia's major U.S. operators include ASA (38 in operation, 76 on order), Comair (12 in operation and 40 on order), Skywest (9 in operation and 16 on order), Westair (16 on operation and 40 on order), NPA (5 in operation), Air Midwest (10 in operation, 14 on order) and Midway (12 on order). Continental Express ordered 50 airplanes; just 36 were delivered before it went into Chapter 11. For a more detailed discussion of market shares see Chapter IV.

turboprops, which purports to substitute the Bandeirante in the 10-20 seat class of commuterliners (the last Bandeirnate was assembled in late 1989). Development started in 1985-86, and due to political and other considerations, Embraer and the Argentine Air Force signed an agreement in 1987 to co-develop and produce the new plane.[19] The inaugural flight was in mid 1990, with a six-month test-flight program delay due to production problems at Fama and technical problems with the development of the entirely new Garret engine (including its installation, due to its pusher configuration), among others.[20]

2.22 The CBA-123 remains at the prototype stage after having failed to translate the 156 paid options it had secured by mid 1990 into firm sales, fundamentally because of its relatively high price (US$ 5.5-5.8 million).[21] The Vector's performance characteristics--short take-off distance (important for regional-aviation operators), fast climbing rate, high cruising altitude and speed (350 kt with a full payload), long range (900 miles, compared to the Bandeirante's 240) and low cabin noise and vibration levels due to the rear-mounted power plants (with the prop plane being 12 feet from the nearest seat row)--appear so far to have been insufficient to compensate for the price of the aircraft.[22]

2.23 Embraer is currently undertaking (at a slowed down pace due to scarcity of resources) the development of a stretch version of the Brasilia--

---

19/ "According to the agreement with Embraer, Fama would have to expand its capital and invest US$ 100 million, one-third of the total investment. Fama would have to upgrade its technical capability in order to manufacture a simiiar proportion of the plane. Assembly lines would be installed in both plants, and one of the five preproduction aircraft would be assembled in Cordoba...The Argentine part felt behind schedule and Fama's share was reduced from 33% to 23%." See Air Transport World, September 1990.

20/ See Air Transport World, September 1990. The Garrett engine itself offers, according to the manufacturer, 30% lower specific fuel consumption and 53% increased power-to-weight ratio than its predecessors. The pusher design requires from the new engine an in-line reduction gearbox and propeller, and a full authority digital engine control. See "Vector Pushes Ahead with TPF 351," in Flight International, December 4, 1990.

21/ The US$ 25,000 options were from 18 commuter and corporate operators in 13 countries, including 36 from Argentina, 30 from Brazil, and 30 from Ontario Express (Canada).

22/ Similarly for its advanced systems (Electronic Flight Instrumentation, Engine Instruments and Crew Advisory, and the [Bendix] Full Authority Digital Engine Control), high safety standards (it is the first 19-seater certified according to jet-like FAR-25 regulations), and fuel economy (it is supposed to break even with less than 9 passengers on board). A regional operator at the 1990 Farnborough Air Show noted that "..the aircraft and its performance has been excellent. The cockpit design is one of the best and the projected operating cost of the aircraft [l]ooks very good. But Embraer has gone way over the US$200,000 per seat threshold at US$ 4.8 million in an industry that does not have an abundance of funding." See Aviation Week and Space Technology, September 10, 1990.

with jet engines rather than turboprops.[23] The EMB-145 original project was a 45-seat fan jet specifically conceived for the regional airline use. It called for 75% of parts and systems of the Brasilia to be retained, in order to keep price and operational costs low; a further by-product of the communality would be the short development time. In mid 1989, Embraer's product prospectus was predicting the EMB-145 entering airline service in 1992, with the first flight in 1991. In early 1991 Embraer had "well over 300 letters of intent and options for the EMB 145 from operators in 13 countries."[24] Comair, a Cicinati-based regional carrier appeared then to be the launch carrier, with a purchase option of 60 of these aircraft.

2.24 Yet between the time the EMB-145 was announced at Le Bourget air show in 1989 and end 1991, there were major design changes introduced in the aircraft. The first design was the one with the greatest degree of communality with the Brasilia, including the wing's basic structure and the fuselage. Development time would be two years, development costs would amount to US$ 250 million (to be financed by major systems' suppliers) and the selling price would be US$ 11.6 million. At end 1990, however, the transonic wind tunnel tests (conducted at Boeing in Seattle) demonstrated that the design chosen would be inconsistent with performance requirements of a pure jet. The new design introduced in early 1991 included new wings derived from the CBA 123, turbines placed under them (as opposed to over the wings as the original design called for) and new landing gear. Aircraft delivery was, as a result, postponed by an year to end 1993.

2.25 Again at the end of 1991 a new configuration was announced, with changes in wings, engine position (now placed in the rear), a longer fuselage, among others. Although the aircraft adds a new row of seats (increasing passenger capacity to 48), take-off weight increased considerably (16.4% since the first design), but paid cargo is 10% less. First deliveries are now expected to be in 1995, and are contingent on Embraer finding risk-sharing partners that, for example, would be willing to manufacture the wing. Even if able to finance the EMB-145 development, the jet will be facing stiff competition from early entrants, including Canadair RJ and the SAAB-2000 fast turboprop.[25]

2.26 Embraer's recent history can be thus encapsulated. Buoyed by the international success of both Bandeirantes and the Brasilia from mid 1970s to mid 1980s, the company decided to develop a top performing 19-seater to substitute the Bandeirante--the CBA 123; and to design, within a relatively short lag, a regional jet, a stretch version of the Brasilia. From an engineering standpoint, the 123 is a success--a state-of-the art pusher prop,

---

23/ The idea for this new stretch model with jet engines was suggested by one of Embraers clients.

24/ See "Transonic Wind Tunnel Tests Completed for Brazilian EMB-145 Regional Jet," in Aviation Week and Space Technology, April 1991.

25/ This discussion of the EMB-145 follows the article "A Genese do Jato," in Jornal do Brasil, nov. 25, 1991.

with the most advanced avionics in the industry, and with performance characteristics that are quite impressive. Yet, its selling price is over US$ 5.5 million--breaking the US$ 200,000 per seat profitability benchmark. The 123 has yet to be marketed successfully and in the meantime Embraer ran out of resources to keep on financing its regional jet development activities.

2.27 Embraer now faces a critical juncture. It has two commercially successful aircraft (in addition to the Piper line): the Brasilia and the military trainer Tucano, which may still bring large sales. The tactical fighter AMX has yet to find a buyer other than the Brazilian and Italian Air Forces, the former having slow down the rate of delivery.[26]

2.28 It is likely that Embraer incurred in two significant strategic mistakes after the mid 1980s in attempting to complete its family of commuter liners. First, it decided to substitute the Bandeirante with a relatively expensive and highly sophisticated aircraft, introduced at a time when profit margins are leaner in the airline industry. It could be argued that an updated version of far less expensive Bandeirante would have been the preferred course of action, avoiding Embraer from outpricing itself from the 19-passenger market. An alternative would have been for Embraer to team up with a competent and financially strong partner to both co-design and co-produce the aircraft. Now Embraer (and Fama) may be forced to price the aircraft below costs during the most intensive part of the learning period, to guarantee a large enough production volume to internalize dynamic economies of scale. Neither Embraer nor Fama appear to be in a position to afford this course of action.

2.29 Second, Embraer started to develop a regional jet at a time when it was already deeply in debt with the development of the Brasilia, the CBA-123 and other projects. Embraer's need of adding to its product line an aircraft of larger seat capacity could have been satisfied with a fast turboprop stretch version of the Brasilia, as opposed to a jet. The argument for a jet is that a 400+ kt cruise speed would "increase hub catchment area and is more than adequate for the short to medium stages flown by most feeder lines and low density point-to-point connections."[27] Yet, it is unclear why a fast turboprop would not perform similarly, with flight times nearly that of a regional jet. Moreover, the turboprop option would imply lower development costs and time, potentially greater communality with the Brasilia, and a far lower probability of design problems that the EMB-145 has faced in the recent past. In view of Embraer's overindebtedness and difficulties of financing new projects (see Chapter IV), and the importance of timing in market-launching a product in an increasingly crowded field, the turboprop stretch might have been a wiser course of action.

26/ A sale of 38 AMX to Thailand worth US$ 757 million (over a ten-year period) was canceled in mid February 1992 by the Thai Government due to budgetary reasons and a lessening of tensions in the region. See Jornal do Brasil, February 14, 1992.

27/ Company literature on the EMB-145, June 1989.

III. EMBRAER'S TECHNOLOGICAL STRATEGY AND PERFORMANCE.

3.01 Embraer's technological development efforts can be characterized as part of a long-term strategy to progressively accumulate knowledge and become proficient in aircraft design and manufacture. One can argue that discontinuities did occur (particularly when the company embarked in the near simultaneous development of the AMX and the Brasilia); but they were much less pronounced than what appears at first sight. Certainly, Embraer did not exactly follow the development paradigm of most emerging aircraft industries, which "begin with maintenance shops, move next to the assembly of imported planes, and to the manufacture under license of military planes for the local market," with some eventually doing subcontract work for major aircraft producers, often under offset arrangements.[28] By contrast, Embraer focused since the beginning in the design and manufacturing of airframes, and systems integration and testing. Not that it wasn't ever involved in pure assembly operations of both military and civilian planes, or in subcontract work. Yet these were never the company's main activity; moreover they were used to obtain key skills and knowledge for the firm to undertake its core activities.

3.02 Embraer was able to take such a course due to strong design capabilities at CTA (which were then transferred to the company) and the ability of drawing from a relatively large and well-trained pool of aeronautics engineers that were already present in Brazil at the time of Embraer's inception. Still, both due to its inherent difficulties and in order to be able to market its products broadly, the company never attempted to manufacture or contract out locally key components or systems, such as engines and avionics. Nor did it try to "indigenize" individual parts and components in an ad-hoc manner, due to the large variety and small numbers of each, which would make it uneconomical to produce locally or in-house. Yet in one fundamental aspect Embraer's technological strategy failed as it approached maturity in the mid 1980s: as argued in the previous chapter, it let designers and performance-focussed officials have an inordinate decision-making power, at the expense of aircraft financing and marketing requirements.

A. Embraer's Early Period

3.03 Embraer's ability to design was the product, initially, of CTA's efforts at developing the Bandeirante. At start-up, CTA's Bandeirante team, comprising 150 engineers and technicians, was transferred <u>in totum</u> to Embraer. This move appeared to be quite effective as a mechanism of transferring project design technology[29]. Still, the original team, though they had

---

28/ See R. Moxon, "International Competition in High Technology: The Brazilian Aircraft Industry," in <u>International Marketing Review</u>, Summer, 1987, p. 16.

29/ Aircraft design technology is, to large extent, of tacit, uncodified nature, "embodied" in teams of technical personnel. Transferring such technology involves moving design teams or "pairing" teams to work side-by-side. See the discussion in "Introduction," N. Rosenberg and C.

designed the plane and manufactured its first prototype, lacked the necessary production experience. Faced with a 80-plane order for the Bandeirante from the Air Force, Embraer didn't have the production skills to fulfill it. Although it was able to procure equipment, and recruit and train production workers from metalworking and other firms[30], acquiring production knowledge was far more difficult.

3.04 To produce the Bandeirante on an industrial scale, Embraer took advantage of the licensing agreement signed with Italy's Aermacchi for the production of a small jet trainer and fighter, the Xavante. Aermacchi's contract allowed Embraer to absorb critical production knowledge in tracing technology, assembly of planes, organization of procurement of materials, quality control, technical documentation, organization of assembly lines[31]. In addition to transferring these technologies, Aermacchi committed itself to furnish technical assistance for the production and design improvements of the Bandeirante for 10 years (thus, for instance, Embraer staff learned with Aermacchi engineers how to design major parts of the Bandeirante at the post-prototype stage, such as integral tanks)[32]. Italian and Brazilian engineers and technicians worked side-by-side for a considerable period, ensuring the acquisition of the required technology. It appears that this was the critical step needed for launching the Bandeirante on a serial basis.

3.05 Other mechanisms were used also to improve Embraer's know-how, including the agreements with Northrop and Piper. The agreement with Northrop was an additional important step in the acquisition of production knowledge. It was an offset contract Embraer signed in 1974 for the construction of 100 F-5 vertical fins, rudders, wings and belly pylons, against the procurement of 50 F-5 by the Brazilian Air Force. A number of major technologies were learned in the process, including chemical milling (which became of significance in the fabrication of the Xingu and the Brasilia), metal-to-metal and honeycomb (structural) bonding, and generally, the handling of composite material. In addition, the contract also forced Embraer to improve on its tool design, quality assurance and other production techniques, while stimulating the use of numerically-controlled machine tools.

3.06 The Piper cooperation agreement was of a fundamentally different nature.[33] Embraer made clear to the U.S. companies that then dominated the

---

Frischtak, eds., The International Transfer of Technology: Concepts, Measures and Comparisons, Praeger, New York, 1985.

30/ See R. Ramamurti, op.cit., pp. 184-5.

31/ From an interview with G. Pessoti, Embraer's Technical Director and chief designer, cited in R. Ramamurti., op.cit., p. 185.

32/ Ibid., p. 185.

33/ On the Piper-Embraer agreement, see Jack Baranson, North South Technology Transfer: Financing and Institution Building., Lomond Publications, 1981, and R. Ramamurti, op.cit., pp 189-91. This agreement is an example of a local company with strong government support negotiating better terms when

Brazilian market of general aviation aircraft (Cessna, Beech and Piper) that the government would effectively keep off all foreign producers except for the one which entered into the agreement (which it did by raising tariffs from 7 to 50% and introducing non-tariff barriers). Three essential features of the agreement were: (1) no royalty payments, (2) Embraer's right to make modifications which it deemed appropriate to the imported models, and (3) a progressive nationalization of the components of the aircraft, which was expected to reach 70-75 percent for all models. Although Cessna had the largest market share, it was Piper which agreed to the conditions in return for a percentage return on components shipped to Embraer (over a ten-year period).

3.07 Initially, Piper sent kits for Embraer to assemble, paint, test flight, deliver (rechristened with Brazilian names) and guarantee. Over time, Embraer introduced design changes and was able to supply or locally subcontract a sizable proportion of parts and components. Compared to the arrangement with Aermacchi, much less valuable production technology was supplied in the framework of the Piper agreement; after all, the Piper line of planes was relatively less sophisticated than the Xavante jet, and Embraer already manufactured more advanced aircraft[34]; still, it has been noted that Embraer accessed "significant transfers of design data and production technology."[35] Probably more important was the know-how Embraer absorbed in the marketing of aircraft and post-sales servicing, which Piper had extensive experience.

3.08 By the mid 1970s Embraer had acquired significant knowhow in aircraft design, manufacturing, commercialization and servicing. Knowledge was absorbed in a purposeful and systematic way, with each project providing important technologies to the next. None of Embraer's initial projects were financed by the company (they were generally underwritten by Brazilian Air Force, with the exception of the Ipanema, where the Ministry of Agriculture paid for the design work); nor were they designed in-premise (although all suffered design improvements, some of them major). Both the Bandeirante and the Ipanema were undertaken at the CTA; the Xavante at Aermacchi's and Piper planes were, of course, Piper projects.

3.09 The company's first project undertaken entirely on its own, both in terms of finance and design, was the Xingu. Although commercially unsuc-

---

the domestic market is of interest to the foreign supplier (on the size of the domestic market for general aviation aircraft see Chapter II). Embraer had three alternatives: it could develop its own models, it could manufacture foreign products under license or negotiate an industrial cooperation agreement. It chose the latter in order to achieve rapid market penetration while improving its own capabilities in areas which it had little experience (such as in the provision of after-sales assistance to buyers).

34/ R. Moxon, op.cit., p.16.

35/ See D. Mowery, Alliance Politics and Economics -- Multinational Joint Ventures in Commercial Enterprises, Ballinger, Cambridge, 1987, p. 117. See also K. Crane and A. Gilliot, "The Role of Western Multinational Corporations in Technology Exports: the Aircraft Industries in Brazil and Poland," Unpublished Manuscript, The Rand Corporation, 1985.

cessful (only 104 units were sold), the Xingu provided an important stepping stone to the Brasilia. Contrary to the Bandeirante, the 6-passenger Xingu was a pressurized plane; Embraer's ability to design and manufacture pressurization systems originated with that aircraft. Similarly, the Xingu introduced T-shaped tail fins to improve aerodynamic performance, a geometry which was later adopted by the Brasilia. Following the Xingu, Embraer designed and built in a relatively short time span (two years) the Tucano trainer to Air Force specifications, which required it to emulate the conditions generally found in jets (ejection seat, single power lever).

B. Embraer's Technological Efforts in the 1980s.

3.10 Embraer's efforts in the last decade changed scale. Although both the Xingu and the Tucano projects were undertaken in-house, they were relatively small when compared to the development of the AMX and the Brasilia (which overlap for most of the 1980-85 period), and that of the CBA-123 in 1986-89. These were costly projects, with the AMX funds originating in the Air Force and those for the Brasilia and CBA program coming from Embraer (more precisely from commercial banks, in the form of loans). These efforts reflected, inter alia, a considerable commitment to formal R&D and, to a lesser extent, in fixed assets, with development being particularly intensive in the final stages of these projects (Table 3).

Table 3: EXPENDITURES ON R&D AND FIXED ASSETS

	1983	1984	1985	1986	1987	1988	1989
R&D expenditure	7	12	53	29	43	53	107
% of sales	3.8	7.5	24.2	7.7	9.1	10.1	15.3
Fixed assets	6	19	9	24	28	17	14
R&D/Fixed assets	1.16	0.63	5.89	1.21	1.54	3.12	7.64

Source: Embraer.

3.11 There was significant synergy between the AMX and the Brasilia projects, and both were fundamental to Embraer's ability to design and bring to prototype testing stage the CBA 123 pusherprop. For the AMX and the Brasilia, Embraer was obliged, inter alia, to introduce CAD/CAM systems and sophisticated tooling (such as 5-axis NC machining centers), integrate digital electronics and advanced navigation, communication and identification systems, and make extensive use of composite materials.[36] Embraer's ability to work with high-temperature composites technology, which had matured by the mid 1980s, allowed it in 1987 to compete successfully for a US$ 120 million contract to supply 200 shipsets of 29-feet long outboard flaps made of composite

36/ Of the empty weight of the 110, 121, 312, AMX, 120 and 123, composites made up 2.1%, 2.5%, 3.0%, 4.0%, 10-12% and 17%, respectively.

material, with an option of 100 more, to be used in McDonnel Douglas MD-11. In 1989, the all-carbon fiber-flaps entered series production.[37]

3.12 As argued above, Embraer's technological strategy systematically involved transferring acquired knowledge, skills and capabilities to the design and production of new aircraft. In many ways, the CBA 123 was the "synthesis" of Embraer's technological advances in the previous 5-8 years. The relative sophistication of 123 project was made possible by the previous investments made by Embraer in manufacturing and integrating the relative complex systems which characterize the AMX and the Brasilia. To an extent, however, the CBA project was also "driven" by the presence of specialized skills and endowments accumulated in the process of developing these aircraft. In other words, the technological momentum gained with the AMX and the Brasilia presented Embraer's engineers with an "opportunity" to fully exploit the capabilities acquired, and eventually led to an overdesigned product (in the sense of not respecting market constraints--in this case, price): the CBA-123.

3.13 Not that Embraer's technical staff ignored cost-minimizing possibilities. Just as other producers, Embraer has attempted to design within the family and exploit communalities among aircraft.[38] The advantages of such as strategy are clear: or the producer, it decreases development costs and time; for the user, it saves in maintenance costs (through interchangeability and communality of parts) and training (both for mechanics and flight personnel). Thus, for example, CBA 123 has the same fuselage section as the Brasilia and is a heavy user of composite materials developed in the context of the AMX and EMB120 programs. The 145 regional jet has parts and sections originating from the Brasilia; in its original design, some 70% were common to both aircraft. Yet it is arguable that Embraer designers have not exploited enough aircraft communality, in their search for superior performance (as in the case of the CBA-123) or the prestige of a pure jet (as with the 145).

C. Embraer's Technological Performance

3.14 There is little question that Embraer has acquired substantial and highly valued technological assets. Its competence in design, structural analysis, use of new materials, product engineering, integration of avionics

---

37/ Additional subcontract arrangement from major producers includes the production of small components for the 747 program (from a 1990 contract with Boeing to supply one million dollars worth of wing-related parts). Embraer is attempting to expand its relations with Boeing by becoming a subcontractor for the 777.

38/ Probably Boeing has been the most proficient producer of using the "family" concept to orient its product strategy. See John E. Steiner "How decisions are Made: Major considerations for aircraft Programs," A.I.A.A. Wright Brothers Lectureship in Aeronautics, Seattle, Washington, August. More recently, Airbus Industries have emphasized the importance to users of the extensive systems communality among its aircraft, particularly when it comes to maintenance and pilot training costs.

and flight commands, prototype testing and fabrication is considerable. Its engineers and technicians have had extensive involvement in techniques such as CAD-CAM[39], metal-to-metal bonding, chemical milling for weight reduction and optimization of skin panel structures, as well as in composite materials manufacturing. The acquisition of these assets was the result of purposeful and well directed efforts at transferring (generally disembodied) technology through a variety of mechanisms (as noted in the previous section), investments in training and R&D, as well as the progressive accretion of technologies acquired in the process of developing and producing a succession of aircraft. What follows is a brief discussion of achievements in key areas of aircraft design, development, testing and fabrication.[40]

3.15 Aerodynamics. A critical feature in aircraft design is establishing its aerodynamic coefficients, particularly of the wings and their junction with the fuselage. In the 1930s, Nasa's precursor (Naca) developed and classified an extensive family of wing sections, whose aerodynamic characteristics were explicitly related to performance objectives. For both the Bandeirante and the Xingu, Embraer adopted unmodified Naca's sections. For the Brasilia, Naca sections were modified, which required substantial wind tunnel testing to ensure that aircraft performance was not put in jeopardy. For the AMX and the CBA 123, Embraer has modified third generation Medium Speed (MS) wing sections, also originally developed by Nasa, and is now able to generate its own wing sections.[41]

3.16 The definition of the aircraft geometry is approached generally by a method of successive approximations: the initial geometry of the wind-tunnel model is defined ex-ante, and is codified in well-known manuals relating the geometry to the aircraft performance. Subsequent parameters are modified by the results of wind tunnel experiments, and eventually of prototype flight tests. Most improvements experienced by Embraer in this area have been of computational nature. By contrast, the assessment of pressures and tensions on the aircraft surface, under both static and dynamic conditions, suffered substantial changes. Starting with the Brasilia, Embraer introduced advanced numerical methods (Vortex-Lattice and Pannels) that allows for more detailed knowledge of the stress suffered by the aircraft structure. It avoids building overdimensioned (and heavier) structures to compensate for

39/ This allowed much faster manufacturing of parts, particularly those produced in multi-axis numerically-controlled machinery. Embraer has the sole five-axis milling machine center in the country and has upgraded machining operations through a system of distributed numerical control.

40/ The discussion on aerodynamics, structural analysis and development, materials, product engineering, avionics and flight testing, draws heavily from A. de Souza Cabral, "Analise do Desempenho Tecnologico da Industria Aeronautica Brasileira," Ph.D Dissertation, Instituto Tecnologico da Aeronautica, 1987, preliminary version, Chapter IV.

41/ The second generation, developed in the 1940s and 1950s, were called General Aviation Wing or Low Speed wing sections. To help in the computational work Embraer has used both the BIDIM and TRANSEP mathematical models and related software, the latter fit for higher speeds. See A. Souza Cabral, op.cit., pp. 91-93.

lack of information; the new methodology also minimizes reliance on costly and time-consuming wind tunnel testing[42]. Finally, tunnel testing models evolved from non-motorized wood structures (the Bandeirante and the Xingu) to motorized metallic ones. Combined, they resulted in improved aerodynamic coefficients for aircraft with basically the same characteristics and missions (Table 4).

Table 4: AERODYNAMIC COEFFICIENTS OF EMBRAER'S AIRCRAFT

Aircraft Type	LC Max a/	L/D Max b/	DC min c/
EMB-110 Bandeirante	2.2	11.4	0.060
EMB-121 Xingu	2.2	12.2	0.062
EMB-120 Brasilia	2.3	12.6	0.049
CBA-123 Vector (est.)	2.8	16.4	0.45

Source: A.S. Cabral, op.cit., Table IV.3.

Notes: a/maximum lift coefficient; b/ -- maximum aerodynamic efficiency or gliding ratio; c/ minimum drag coefficient at cruising conditions.

3.17 Structural Analysis and Development. For the analysis of the Bandeirante, the CTA team used (what was then) the frontier method of finite elements. Its success led Embraer to develop a number of application softwares (approximately 20) for structural improvements in the aircraft. Subsequently, Embraer combined the Nastran software for structural calculus (developed in the 1970s by a Nasa-commissioned firm) and its own applications (which averaged 100 programs for the AMX and the Brasilia, and 50 for the CBA-123). The aircraft models evolved from hand-made (prior to 1979-80) to CAD-based (starting with the Brasilia). Significantly, CAD was introduced in Embraer only a year after it was made available worldwide for the purpose of structural analysis. The time required for such analysis decreased from 3-4 months to two weeks (the latter for the CBA-123); in case of dynamic trials or tests, the time taken shrunk from a matter of months (8 for the EMB-111, 2 for the EMB-110) to 4 days (for the EMB-120). Reductions of similar magnitude (from a few months to a few weeks) were obtained in the analysis of vibrations. For vibration tests on soil, the time reduction was also striking: from 1 month (for the EMB-110) to 2 days (for the EMB-120).[43] Finally, the type of aircraft structure built by Embraer evolved from "safe-life" (which is

42/ See A. de Souza Cabral, op.cit., p. 96.

43/ Vibration and noise are closely related phenomena. The increased quality in vibration analysis allowed for low noise levels in the EMB-120 compared to the EMB-110 and 121. The Brasilia aircraft was 10dB below FAR-25 specifications for external noise levels, and 7dB below the SAAB and Dash competing aircraft in internal noise levels.

supposed to withstand tensions and pressures during the aircraft useful life--used for the EMB-110); to "fail-safe" (where failure of a primary structure does not lead to the aircraft crashing--used in the EMB-121); and, in response, to changes in regulations, to "damage tolerant" (which is supposed to take into account problems of corrosion, metal fatigue etc.--used in the EMB-120, AMX and CBA-123).[44]

3.18 Materials. The improvement of aircraft performance is increasingly dependent on the use of lighter and more resistant materials. Since Northrop's offset agreement, Embraer has worked with new materials, though their extensive was introduced with the AMX and the EMB-120 projects. These aircraft utilize, among others, titanium plates; aluminum honeycomb bonded under high temperature to aluminum plate; and pre-impregnated fabric with fiberglass epoxy resin bonded also under high pressure with aramicyde and carbon fibers. These new materials present substantially greater flexibility, specific resistance and tenacity to fracture (2-3 times that of conventional materials used in the EMB-110); they also resulted in lower empty weight and improved range for aircraft.[45]

3.19 Product Engineering. The detailed specification and documentation of all aircraft parts, subsystems and systems through designs, diagrams and lists, constitute the core of product engineering. Mediawise, such documentation evolved from paper, metal and cronaflex, to CAD-CAM. Both the AMX and EMB-120 projects, and that of the CBA-123 and EMB-145, utilized advanced CAD-CAM systems. Improvements are observable not only in the increased consistency and reliability of electrical and other systems' diagrams, for example, but more broadly in indicators such as the proportion of non-valid drawings and the average number of modifications per drawing (Table 5).

Table 5: PROFICIENCY IN AIRCRAFT DRAWINGS

Models	Ipanema	Bandeirante	Xingu	Tucano	Brasilia
Non-valid drawings(%)	20.6	8.8	7.5	7.8	7.2
Modif. per drawing	4	3.5	3.0	2.5	2.0

Source: A.S. Cabral, op.cit., Table 4.13 and own calculations.

44/ See A. de Souza Cabral, op. cit., pp. 122-3.

45/ Even during serial production of the same aircraft, the search for improved performance with the use of new materials has continued. In case of the Brasilia, for example, its empty weight evolved from 7,250 kgs to 6,900 kgs between serial numbers 4 and 41, mostly as a result of incorporating such materials. See A.S. Cabral, op.cit., Figure IV.8.

3.20 Avionics. The application of avionics by Embraer have closely followed the movement of the international technological frontier. The Bandeirante avionics, for example, was designed already with the help of U.S. system suppliers in view of their importance for the marketing of the aircraft, and consistent with what was available in the early to mid 1970s. The Xingu, though still using analog-based instrumentation, introduced navigation, communications and identification systems, as well as an automatic pilot of more recent vintage. With the Brasilia and to an even greater extent, with the AMX, Embraer stepped up its use of last-generation avionics, through the use of CRT (cathode-ray tube) indicators and fully digitalized instrumentation, a trend consolidated with the CBA-123. Flight commands evolved from manual-mechanical (Ipanema), to motorized (EMB-110, 121, 312), and then to a combination of servo-hydraulic and fly-by-wire (EMB 120, AMX and 123).[46]

3.21 Flight Testing. Testing procedures are carried out for certification purposes, to validate performance parameters defined ex-ante and to define flight manual procedures. Aircraft certification is a precondition for its commercialization, and therefore of paramount importance to producers. Increasingly, they conceptualize and carry out aircraft development with a view of ensuring that it is certifiable by the regulatory agencies of major markets (FAA, CAA, DGAC, respectively of the U.S., Britain and France). Certification establishes strict lower-bound limits on aircraft quality and performance characteristics, having a pervasive effect on the company's culture.

3.22 The Bandeirante international commuterliner version was the first Embraer aircraft to be submitted to international certification. It imposed far more rigid standards than were asked of other versions (FAR 135 versus the small-aircraft FAR 23 norms). In case of the Xingu, its certification process was used by Embraer a paradigm for the testing of pressurization systems. Subsequently, this was a useful model for the Brasilia, which was the aircraft that faced successfully the most rigid certification norms (FAR-25 passenger transport category). Finally, testing data capture and processing also evolved dramatically: from being manually annotated and calculated to being digitally recorded and processed in real time, with the number of parameters growing from 12 to some 350.

D. Learning to Produce: the Experience with the Brasilia Commuter Aircraft

3.23 It has been argued so far that Embraer's technological strategy involved systematic efforts at accumulating knowledge, skills and overall manufacturing capabilities. Indicators of technological performance are suggestive that such strategy was pursued sucessfully. Embraer's record with the assembly and fabrication of the EMB-120 further corroborates that proposition. The evidence this paper has gathered is based on estimation of "short run" learning curves for the Brasilia (both airframe and fuselage), relating the real costs (in labor hours) per aircraft to indices of production experience (cumulative output, time) on a classical log-linear functional form. The

---

46/ See A. de Souza Cabral, op.cit., pp.151-65.

estimation yields parameters from which the "slope" of the Brasilia learning curve is derived and compared with estimates based on the U.S. experience with aircraft produced during and after World War II (WWII).

3.24 Historically, the notion of the learning curve has been associated with studies of airframe production costs. T.P. Wright was the first to relate functionally (in loglinear form) the observation that direct labor costs decrease as the cumulative number of airframes produced rise.[47] Although the concept of learning curve has been used to explain the cost dynamics of many industries[48], where Wright's model has received general confirmation, it has been used far less often in industrializing countries' contexts.[49] Yet, in principle, there is no reason for the concept to be less

---

47/ See T. P. Wright, "Factors Affecting the Cost of Airplanes," Journal of Aeronautical Sciences, vol. 3, 1936, pp. 122-8. According to Wright, the most important aircraft costs components, in addition to the number of airframes built, were: design factors and the specific materials used in the aircraft; the adequacy of tooling to design; engineering changes once serial production starts; and size and weight of the aircraft. For a systematic discussion see H. Asher, Cost-Quantity Relationships in the Airframe Industry, The Rand Corporation, Santa Monica, July 1956.

48/ Most studies relate, in fact, to the U.S. experience. See, for example, W. Z. Hirsh, "Manufacturing Progress Functions," in The Review of Economics and Statistics, vol. 34, 2, May 1952 and "Firm Progress Ratios," in Econometrica, vol. 24, 2, April 1956, that examine learning effects in machine tools, and suggest that progress in the complex assembling operations of parts is more rapid and consistent than in their machining; L. Rapping, "Learning and World War II Production Functions," The Review of Economics and Statistics, vol.47, 1, Feb. 1965, that studies the "remarkable" growth in the productivity of the shipbuilding industry between December 1941 and 1944, and attributes it to extensive individual and organizational learning from the introduction of mass production techniques and greater levels of coordination in scheduling tasks; N. Baloff, "Start-ups in Machine-Intensive Production Systems," in Journal of Industrial Engineering, vol.17, January 1966, who after studying the steel, basic paper products, glass containers, electrical conductors and electric switching components industries, concludes that learning in machine-intensive manufacture is significant and results from improvements of cognitive skills of process engineers; P.Joskow and G.Rozanski, "The Effects of Learning by Doing on Nuclear Plant Operating Reliability," in The Review of Economics and Statistics, vol. 41, 2, May 1979, that note that technical progress due to learning by doing plays an important role in determining the productivity of nuclear power plants; and E. Sheshinsky, "Tests of 'Learning by Doing' Hypothesis," in The Review of Economics and Statistics, vol. 49, 4, Nov. 1967, according to who efficiency growth is correlated with the level of investment and output in the metal, leather, chemicals, paper, electric machinery and transportation industries.

49/ There are some important exceptions. See, for example, the analysis of the metal-products sector of Colombia in L. Dudley, "Learning and Productivity Change in Metal Products," in American Economic Review, vol. 52, 4, September 1972. See also P. A. David, "The 'Horndal Effect' in Lowell, 1834-56: a short-run learning curve for integrated cotton textile mills," in P. A. David, Technical Choice, Innovation and Economic Growth, Cambridge University Press, 1975, pp.174-191, for a detailed discussion of learning effects in cotton textile mills at a time the U.S. was still an industrializing country.

applicable to these countries' industries. An analysis of the evolution of the Brasilia's direct labor costs corroborates this proposition.

3.25 In the regression analysis below, the total labor costs L* (in labor hours)--LH in case of airframes and Lh for fuselages--of each unit of output is related logarithmically to the direct labor cost of the first fuselage or airframe (Ao); to one or more indices of experience (such as cumulative output, time)--E_i--which purports to capture dynamic economies of scale effects; and to a "rate of output" variable--S_j--which is supposed to reflect standard economies. Similarly for the average total number of labor hours per month and per quarter--LHM and LHQ for airframes, and LhM and LhQ for fuselages. The "learning" and "standard economies" elasticities are respectively m and n. The expression for the short-run learning curve is thus denoted by:

$$L^* = AoE_i^{-m}S_j^{-n}, \quad 0 < m,n < 1 \qquad (1)$$

which can be written in loglinear form as,

$$\log L^* = \log Ao - m \log E_i - n \log S_j \qquad (2)$$

3.26 The multiple regression estimates of equation 2 above are based on 144 observations, starting with aircraft number 6, finished on July 12, 1985, and ending with aircraft number 150, completed on September 23, 1989. All aircraft were produced in the same facility. Data on both fuselage and airframe were available: therefore, all parameters were estimated for both cases (Tables 6A and 6B). Although some authors question the use of log-linear functional forms for estimating "progress" or learning curves for aircraft on the basis that it "[i]s not an accurate description of the relationship between unit cost and cumulative output,"[50] this objection applies to values of cumulative output above 300. Under such a magnitude, the literature suggests that loglinear estimates appear to be accurate. Thus, the loglinear functional form was adopted in all equations.

50/ H. Asher. op.cit., p.v.

Table 6A: LEARNING CURVE ESTIMATES FOR THE BRASILIA a/ 1985-89, Airframe

Eq. Number	Dependent variable b/	Independent variables c/					R-sq	Slope d/
		CUM	M	Q	NUMM	NUMQ		
1	LH	0.39					0.93	76.3
2	LH		0.46				0.88	72.7
3	LH	0.31	0.1				0.94	--
4	LH			0.5			0.89	70.2
5	LH	0.34		0.51***			0.93	--
6	LHM	0.29					0.96	81.8
7	LHM		0.41				0.91	75.3
8	LHM	0.29			0.02***		0.96	--
9	LHM		0.37		0.07***		0.92	--
10	LHQ	0.31					0.97	79.7
11	LHQ			0.47			0.95	72.2
12	LHQ	0.34				0.05***	0.97	--
13	LHQ			0.43		0.05***	0.96	--

Source: Own estimates on the basis of data furnished by Embraer.

Notes:

a/ All coefficients are of negative sign, and unless otherwise noted, statistically significant at the 1% level (on the basis of a two-tail T test);

b/ LH is the total number of labor hours per unit of output; LHM and LHQ are average total number of labor hours spent per month and per quarter, respectively;

c/ CUM is the cumulative number of airframes; M is the number of months; Q the number of quarters; NUMM the rate of production of aircraft per month; and NUMQ is the rate of production of airframes per quarter; * significant at the 5% level; ** significant at the 10% level; *** not statistically significant;

d/ The "slope" of the learning curve indicates how fast learning is taking place -- labor costs decline by (100-slope)% with each doubling of output or time.

Table 6B: LEARNING CURVE ESTIMATES FOR THE BRASILIA a/
1985-89, Fuselage

Eq. Number	Dependent variable b/	Independent variables c/					R-sq	Slope d/
		CUM	M	Q	NUMM	NUMQ		
1	Lh	0.36					0.90	77.9
2	Lh		0.42				0.85	74.7
3	Lh	0.29	0.8**				0.90	--
4	Lh			0.47			0.86	72.8
5	Lh	0.30		0.06***			0.93	--
6	LhM	0.27					0.94	82.9
7	LhM		0.38				0.89	76.8
8	LhM	0.26			0.06**		0.94	--
9	LhM		0.33		0.11*		0.90	--
10	LhQ	0.29					0.96	77.8
11	LhQ			0.43			0.93	74.2
12	LhQ	0.30				0.006***	0.96	--
13	LhQ			0.32		0.05***	0.96	--

Source: Own estimates on the basis of data furnished by Embraer.

Notes:

a/ All coefficients are of negative sign, and unless otherwise noted, statistically significant at the 1% level (on the basis of a two-tail T test);

b/ Lh is the total number of labor hours per unit of output; LhM and LhQ are average total number of labor hours spent per month and per quarter, respectively;

c/ CUM is the cumulative number of fuselages; M is the number of months; Q the number of quarters; NUMM the rate of production of fuselages per month; and NUMQ is the rate of production of fuselages per quarter; * significant at the 5% level; ** significant at the 10% level; *** not statistically significant;

d/ The "slope" of the learning curve indicates how fast learning is taking place -- labor costs decline by (100-slope)% with each doubling of output or time.

3.27 The ordinary least-squares elasticities of the coefficients in equations 1-13 in Tables 6A and 6B were, with a few exceptions, statistically significant[51]; and the explanatory power of the equations is quite high. The results appear to be robust. They suggest <u>first</u>, that for both airframe and fuselage production, the key indices of experience--cumulative output and calendar time--are good predictors of labor productivity gains; when both variables enter the regression equation, the former has a stronger effect and is more significant than the latter[52]. <u>Second</u>, the effects of the rate of output variables are small in magnitude and in statistical significance when compared to the prime "experience indices." Thus, dynamic economies of scale, as expressed by cumulative indices of production or time, seem to dominate static economies of scale, as measured by indicators of output per unit of time[53]. It appears, therefore, that static economies are not very relevant in aircraft production, at least when compared to available dynamic gains. This result is consistent with early work on the manufacture of airframes.[54]

3.28 <u>Third</u>, the estimated elasticity coefficients place Embraer at the production frontier when it comes to the efficiency with which fuselages and airframes are manufactured. For the Brasilia fuselage, its learning curve elasticity (with respect to cumulative output) of 0.36 implies that unit labor costs have been decreasing by 22.1% for every doubling of output.[55] The slope

---

<u>51/</u> Although the variable CUM is positively correlated with measures of calendar time -- M and Q -- problems of multicollinearity have not been detected in the equations. Equations 3 in Table 6A, and 3 and 5 in Table 6B, present time variables with low levels of statistical significance. Yet one does not observe mutually high standard errors in CUM and M, or in CUM and Q, the major symptom of multicollinearity.

<u>52/</u> Other authors have also found that cumulative output to be much more statistically significant than calendar time. See, for example, L. Rapping, <u>op.cit.</u>, and E. Sheshinski, <u>op.cit.</u>

<u>53/</u> Other empirical studies also suggest that the productivity impact of variables related to static economies of scale is not large when compared to learning effects. See, for example, S. Hollander, <u>The Sources of Increased Efficiency: A Study of Du Pont Rayon Plants</u>, MIT Press, Cambridge, Mass., 1965; L. Preston and E. Keachie, "Cost Functions and Progress Functions: An Integration," <u>American Economic Review</u>, vol. 54, 2, March 1964; and M. Lieberman, "The Learning Curve and Pricing in the Chemical Process Industries," Graduate School of Business, Stanford University, May 1983, section V.

<u>54/</u> As H. Asher, <u>op.cit</u>., notes in his analysis, "the rate of production is not taken into account in the relationship between unit man-hour cost and cumulative production. This omission does not mean that the rate of production is assumed to have no effect on unit man-hour cost or unit production cost. Most authorities on the field of airframe-cost work are agreed that the rate of production does have an influence on both types of unit cost. However, it is felt to be of minor importance..." (p.86).

<u>55/</u> This is arrived by calculating $1-(0.5)^m$ where m is the elasticity coefficient. Let the reduced form short-run learning curve be denoted by $L=AE^{-m}$, where AEe^{-m} is an index of experience (in this case cumulative output), and m the elasticity coefficient. When cumulative output is doubled, the ratio of labor hours (i.e., labor costs) after and before the

of both airframe and fuselage learning curves (in cumulative output--equations 1 and 10 on both tables) are very close (in fact slightly better) than Wright's industry parameter of 80%. Moreover, the Brasilia's results come very close to the ones obtained (on average) for the production of World War II and post-War airframes, the former still considered the frontier gains of all time (Table 7).

<u>Table 7</u>: UNIT NUMBER ONE LABOR REQUIREMENTS AND SLOPE OF LEARNING CURVES FOR AIRFRAMES

Type of aircraft	Man-hours per pound at unit number one	Slope (%)
Brasilia	18.31	77.9
WWII:		
Fighters	18.5	79
Bomber	16.0	77
Transports	16.0	77
Post WWII:		
F-1 -- F-12 (average)	19.62	78.3
F-5	16.97	77.5
F-7	16.36	79.0
F-9	22.51	74.0
F-10	21.12	75.8

Source: H. Asher, op. cit., pp. 39 and 67, Table IV.1

3.29 It is true that a sharply declining learning curve could be simply the reflection of inefficiencies in the beginning of the run. Clearly, a relatively high man-hour cost of the first unit allows for a faster rate of productivity gain; conversely, extensive planning and tooling conspire to slow down the decline in man-hour cost. Yet even taking into account or controlling for the number of man-hours per pound at the initial unit, the results still bear out the notion that the rate of learning in the production of the Brasilia is close to what was found for U.S. aircraft manufactured during WWII and the 1950s (Table 7). Moreover, it should be noted that the Brasilia's estimates were for unit number 6 onwards: at that point some learning has already occurred, leaving relatively less to be learned. It could thus be argued that the true slope of the Brasilia is in fact lower than what was implied by its corresponding learning elasticity.

---

doubling of output is equal to $A(2E)^{-m}/AE^{-m} = 2^{-m} = (1/2)^m$. Thus labor costs (or hours) decrease by $1-(0.5)^m$ every time output is doubled.

3.30 What explains Embraer's proficiency in manufacturing the EMB-120, both the fuselage and the complete airframe? Learning effects are often associated with labor-intensive, complex to schedule and coordinate activities.[56] The longer the production run, the more familiar product and process characteristics are to production workers, designers, engineers and managers; hence the progressive accumulation of specific human capital (i.e., specific to that activity). Longer runs also propitiates greater specialization in the use of tools and machines; in airframe production, for example, it allows for the introduction of special tools, high cost dies for presses, jigs for simultaneous assembling and drilling etc. Learning thus becomes the outcome of the cumulative acquisition of skills, including in production planning and organization, and the introduction of more advanced tools and production techniques.[57]

3.31 It is worth stressing that the dynamic gains from longer production runs, however, are not "automatic," irrespective of the effort applied to the acquisition of technological and organizational knowledge. To effectively exploit dynamic economies of scale, requires careful planning and efficient tooling, intensive training of workers, and strong organizational capabilities, all of which Embraer has demonstrated to possess.

3.31 Despite Embraer's impressive technological achievements, they were not sufficient to ensure long-term profitability. As will be argued in the next chapter, a combination of growing development costs and intensifying competition in the world commuter aircraft market, pushed many producers--particularly those poorly capitalized and that were obliged to borrow to finance development expenditures--into major financial difficulties. Most were forced to sharply restructure their operations (and balance sheets), including Embraer. The commuter aircraft industry will emerge from these changes with fewer independent actors, as firms vie to cooperate, share costs and mobilize common resources, to face growing rivalry in a globalized market.

56/ For example, W. Hirsh, op. cit., in his discussion of the machine tool industry, stresses that the opportunities to learn are greater in complex processes.

57/ See the discussion in M. Hirshleifer, "The Firm's Cost Function: A Successful Reconstruction?," Journal of Business, vol. 35, 3, July 1962.

IV. RIVALRY AND COOPERATION IN THE INTERNATIONAL AIRCRAFT MARKET

4.01 The original Bandeirante was designed at CTA was an eight-passenger model.[58] In 1972 two commercial Brazilian airlines ordered a 16-passenger version of the Bandeirante for use on local routes, which had become uneconomical to serve due to the lack of proper equipment. The success of this commercial model, which started operating in 1973 within Brazil,[59] encouraged Embraer to launch the Bandeirante in the international market. In 1975, Embraer undertook its first exports. 5 Bandeirantes and 10 Ipanemas to Uruguay for a total of US$5 million (including airplanes, technical assistance and spare parts). Two more foreign sales were made in 1976--three Bandeirantes to the Chilean army, and three Xavantes to the Air Army of Togo.

4.02 In 1977 Embraer gained recognition as an important new competitor in the international market by exporting for the first time to developed countries--France, the U.K., and Australia; the EMB-110 had been officially certified by France and England. FAA certification in 1978 then allowed the Bandeirante to enter the U.S. market (which was then approximately 50% of the world market for commuterliners). Later on, to support its market penetration efforts, Embraer established a network of sales and service representatives, and set up two major centers abroad: one in the U.S. (in Ft. Lauderdale, Florida) and another in France (at Le Bourget). These units engage in sales, the supply of parts, and the training of pilots and mechanics.

4.03 Embraer's exports have grown steadily from US$5 million 1975 to US$ 137 million ten years later, peaking in 1989 at US$ 368 million (Table 8). During this period (1975-89), exports grew at an annual rate of over 33 percent. Since the mid 1980s, Embraer has been selling aboard two-thirds of its output; by end 1990, its commuter aircraft worldwide market share was in the order of 31%. The importance of export markets in the post-Bandeirante phase of Embraer is epitomized by the fact that the first Brasilia to be delivered went to foreign operators, and that Embraer is now unable to move ahead with its new aircraft for lack of firm export orders.[60] Large up-front

---

58/ The first two prototypes built at Embraer in 1969 and 1970 were also eight-passenger models. However, the Air Force asked for a larger airplane, and in 1970 Embraer turned its efforts to stretch the Bandeirante. The first stretched version was flown in 1972 and could carry 12 passengers. The Air Force ordered 80 such planes (later changed to 60) and 20 of a military cargo and parachute troop transport version with a still longer fuselage and more powerful turbines.

59/ In 1976, when five new local carriers entered to serve the internal market, they all chose the newest version of the Bandeirante, which by that time was an 18-passenger model.

60/ Not that Embraer order book is empty; it is just not firm enough. By end 1991 the turboprop commuter aircraft order book from U.S. customers totaled 1,598 units (including 986 options) worth US$ 10.6 billion. The proportion of units and value among market leaders were: Embraer (21%, 19%); British Aerospace (19%, 15%); SAAB (17%, 24%); ATR (10%, 17%); Other (33%, 25%). See Airport Transport World, December 1991, p. 63.

orders have become essential to help fund and ensure that development costs are paid back; and long production runs are needed to guarantee the producer is able to dilute fixed costs, and progressively lower variable charges (particularly labor) by exploiting learning economies of scale.

Table 8: Embraer Sales in the International Market
Various Years a/
(current US$ million)

	1977	1980	1985	1986	1987	1988	1989	1990	1991 a/
Exports	5	85	137	247	333	204	368	262	139
Exports/ Net sales b/	6	50	63	65	70	62	64	63	63

Source: Embraer.

Note: a/ Net sales from Table 4; b/ -- up to November 1991.

4.04 The importance of the international market for the viability of new projects both at the development and the production stage is demonstrated by Embraer's difficulties with its two new aircraft. The CBA-123 is ready for serial production. Yet start-up costs are such that it is nearly impossible to launch the aircraft solely on the basis of domestic Brazilian and Argentine orders, short of a combined jumbo order of the Air Forces (say, 70-80 aircraft). Even if Embraer and Fama (the Argentine partner) were to consider developments costs sunk (and therefore irretrievable), and charge for the aircraft solely on the basis of total production costs (ex-development outlays), still substantial sales volumes would be required for losses to be avoided. Such orders are in a scale that are a multiple (7-8 times) of the combined Brazilian and Argentine domestic markets for 19-passenger aircraft.

4.05 In case of the EMB-145 regional jet, Embraer has been unable to proceed in the absence of firm market prospects. The reason is clear: after borrowing to fund the development of the CBA-123 (and the EMB-120) and exhausting its leverage capacity, development costs have to be fully charged to customers. And these have to commit to an aircraft at the early development stage if the project is to proceed.[61] In the past, development could be undertaken first and firm sales ensured at a later date. Yet as commuter aircraft have become more sophisticated and (generally) larger, total development costs have escalated--they currently range from US$250 to US$ 650 million (the latter figure for the SAAB 2000). Generally, at least 300 units

61/ In the case of the SAAB 2000, with first deliveries planned for 1992, firm orders were placed as far back as 1988 by Crossair (25 plus 25 options), followed by NorthWest Airlink Express (10), and Air Marshall Islands (3 plus 3 options). A US$ 316 million loan from the Swedish Government further bolstered the US$ 650 million development program.

have to be sold for a new generation of commuter aircraft to break even.[62] No domestic market (with the possible exception for the U.S.) can support such volumes. This fact has put strong pressure on producers to design for the international market on the basis of actual or perceived operators' preferences.

A. Competition in the International Commuter Aircraft Market

4.06 An aggressive posture in international markets is becoming essential for product development and launch. Such behavior is reflected in a continuous stream of new products. Competition in all market segments -- 10-19 passengers, 20-45 passengers and 45+ -- has intensified at a time when new aircraft orders have slowed down, the composition of order books have changed away from firm sales and second-hand aircraft prices have lowered substantially.

4.07 This trend of intensifying competition in the industry is not new, and can be traced to the early 1980s. Two periods of accelerated growth in U.S. commuter passenger traffic (1977-79 and 1982-84, with average annual growth of 20%) shifted out demand by U.S. regionals. Deliveries expanded significantly in 1979-82, and stimulated producers to bring in new or improved aircraft. At the same time, Embraer's rapid U.S. market penetration highlighted the growth potential of the commuter aircraft market, and the opportunities open to newcomers.

4.08 When Embraer entered the international market with the Bandeirante in 1975, it met little resistance. In the U.S., the commuter market was not perceived as significant in size. General aviation light aircraft and corporate aircraft shipments in 1981 totaled US$ 1.8 billion to 2.0 billion, four times that of commuters.[63] The industry then was made up of few incumbents and outdated products in a stable arrangement. In the 10-19 passenger niche, Fairchild had introduced its Metro III in 1970; Beech 99 series was introduced in 1968, discontinued in 1987, and for three years the company was out of the market before starting to deliver the C99 version in 1981. The only other competitor was de Havilland's Twin Otter.[64]

4.09 Since then the environment has changed significantly. An indication of how turbulent the U.S. market has become is given by the evolution of the shares of aircraft <u>in operation</u> in major seat categories. Since 1983, in no seat category shares have been stable. Entry has tended to erode the position of incumbents. This is most clearly observable in the 20-

---

62/ Take the case of the Dornier 328: it is estimated that 360 units will have to be sold before it breaks even. See Air Transport World, December 1991, p. 3.

63/ See R. Sarathy, op. cit, p. 73.

64/ Other market segments were at least as stable. The 20-45 market was dominated by Shorts 330 and Fokker 27, whereas newer commuter aircraft models with more than 45 seats were basically unavailable (Nihon's YS-11 and the Convairs 580/600/640 were the only available).

45 seat category, where the share of aircraft in operation oscillates significantly for all models (Table 9). In the 10-19 seat category, only Fairchild's Metro series escapes large share variance after "entry" of BAe Jetstream 31 and Beech 1900 (that is, their emergence as significant market participants); whereas in the 45+ segment, "entry" of the Fokker F28 in 1984 and BAe 146 series in 1985 introduced share dynamism where before prevailed a relatively stable arrangement.

Table 9: OPERATING COMMUTER AIRCRAFT BY SEAT CATEGORY
PERCENTAGES OF NUMBER OF AIRCRAFT, 1982-90 a/
U.S.

Seat Cat.	1982	1983	1984	1985	1986	1987	1988	1989	1990
10 to 10 Seat									
Fairchild Metro Series	32	31	36	32	36	38	38	35	32
Bandeirante	20	21	21	14	16	13	10	9	8
Twin Otter	23	21	21	17	12	10	11	11	11
Beech 99	25	23	22	17	16	12	8		
BAe Jetstream 31				13	11	17	20	28	28
Beech 1900				7	9	10	12	17	21
Casa NC 212		4							
Subtotal	100	100	100	100	100	100	100	100	100
20 to 45 Seat									
Shorts 330/360	65	67	62	51	46	36	23	20	17
Fokker F27	35	33	38	36	36	10	7	8	7
Saab SF 340				13		22	22	21	21
Dash 8					18	11	13	13	11
Brasilia						12	20	23	29
ATR 42						8	15	15	16
Subtotal	100	100	100	100	100	100	100	100	100
>45 Seat									
Dash 7	47	32	29	28	32	38	39	44	74
Nihon YS 11		20	21	19	20	17			
Fokker F28			9	14					
BAe 146 series				7	11	20	35	33	26
Convair 580/600/640	53	48	41	32	38	25	25	23	
Subtotal	100	100	100	100	100	100	100	100	100
TOTAL	63	70	58	65	62	77	73	68	65
All other	37	30	42	35	38	23	27	32	35
GRAND TOTAL	100	100	100	100	100	100	100	100	100

Source: Regional Airlines Association (RAA) and AvStat Associates

Note: a/ Aircraft singled out by RAA statistics by their relative importance in the market.
Metro by Fairchild; Twin Otter and Dash by de Havilland of Canada;
Convair includes 580/600 and 640.

4.10 Similar indications of more intense competition in the regional aircraft industry can be inferred from world actual market share data. Instead of shares of operating aircraft, available data is for shares of aircraft deliveries (but only for the 20-45 and 45+ seat segments). This is a more sensitive indicator of shifts in the competitive position of aircraft in different market segments. Even more than in the U.S. experience, all segments are characterized by substantial share turbulence, with large numbers of aircraft entering and exiting the market (Tables 10 and 11).

Table 10: DELIVERED COMMUTER AIRCRAFT BY SEAT CATEGORY
PERCENTAGES OF NUMBER OF AIRCRAFT, 1980-90 a/
(World Totals)

Seat category	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
20 to 45 Seats											
Shorts 330/360	11	13	15	18	22	22	21	20			
Fokker F27	89	87	85	82	77	70	60	52	56		
Dash 8-100					0	2	5	7	11	25	24
Saab SF-340					1	5	8	10	13	27	27
ATR 42						0	3	6	10	23	23
Brasilia						1	3	5	10	24	25
NC 235								0	1	1	2
Subtotal	100	100	100	100	100	100	100	100	100	100	100
>45 Seats											
Dash 7	8	13	16	15	16	16	15	15	13		
BAe HS-748/ATP	41	39	37	36	34	33	31	30	28	42	7
Lockheed L382/L100	15	14	13	12	11	11	10	10	9	14	
Fokker F28	36	35	34	35	35	35	35	34	31		
BAe Series 146				1	3	5	8	11	13	25	39
Fokker 50									5	12	25
Fokker 100									1	6	16
Dash 8-300										1	8
ATR 72											5
Subtotal	100	100	100	100	100	100	100	100	100	100	100

Source: ICAO Annual Reports of the Council, 1986-1990.

Notes:

a/ Breakdown of the ATR fleet into ATR-42s and ATR-72s were estimated based on companies' figures of December 1990; estimated breakdown of the Dash-8 fleet into series 100 and 300 based on company's figure as of July 1991.

4.11 Table 11 summarizes the intensity of entry and exit in the world commuter aircraft market. It stands out that in the 45+ category, there have been more entries in the 1983-90 period (five) than in the previous twenty or so years. Data for the 20-45 seat segment is even more striking; more than twice as many entrants in the more recent period. This particular segment evolved from a duopoly to a highly contested oligopoly. More recently, further entries in the 20-45 and the 45+ passenger segments suggest the market will be characterized by more and not less competition in the 1990s: in particular, with the "roll outs" of the BAe Jetstream 41 and the Dornier 328, the 20-45 segment appears particularly crowded. At the same time, the ATR 72, Canadair RJ and the SAAB 2000 are stimulating significant rivalry in the 45+ segment. Finally, upgraded versions of existing aircraft continues to come to all segments.

Table 11: ENTRY/EXIT IN THE WORLD COMMUTER AIRCRAFT MARKET a/

Seat Cat.	1960-82	1983	1984	1985	1986	1987	1988	1989	1990
20-45	+Shorts 330 +Fokker 27		+Saab 340	+EMB-120 +Dash 8-100	+ATR 42		+NC 235 -Shorts 330	-Fokker 27	
45+	+Dash 7 +BAE HS-748 +Lockheed +Fokker 28	+BAe 146					+Fokker 50 +Fokker 100 +ATP	+Dash 8-300 -Dash 7 -Fokker 28	-Lockheed +ATR 72

Source: Table 10.

Note:

a/ a "+" meaning an individualized entry and a "-" and exit into the "other aircraft" statistics.

4.12 An additional indication of the intensity of competition in the commuter aircraft market is given by its price structure. Per seat prices for aircraft in both 20-45 and 45+ seat categories average some US$ 223,000 and US$ 209,000 respectively (Table 12). Though price variance is not large, it is significant in both markets as relative newcomers (particularly ATR, but also ATP) are pricing their aircraft at aggressive levels. Over time, the tendency for producers to match each others conditions (in a "Bertrand" type oligopolistic behavior) has led to thinner profit margins and a deteriorating financial performance.

Table 12: 1992 PRICES OF COMPETITORS WITH SIGNIFICANT MARKET SHARES IN 1990

Aircraft model	Price in million US$	Maximum number of seats	Price per seat
≤ 45 Seats			
Brasilia	7.6	30	253,300
Saab 340	8.8	37	237,800
Dash 8 - 100	9.65	40	241,250
CN 235	9.9	44	225,00
ATR 42	10.6	50	212,000
45 + Seats			
Dash 8 - 300	12.5	56	223,200
Fokker 50	12.5	58	215,500
ATR 72	12.9	74	174,300
ATP	13.7	72	190,300
Fokker 100	28.5	120	237,500
BAe Series 146-300	25.9	122	212,300

Source: Commuter Regional Newsletter - International, Vol. V, number 8, Feb. 1992.

4.13 The fact that the market has turned increasingly competitive explains to a large measure the financial difficulties of major aircraft producers. They have had to restructure operations while relying on Government subsidies to survive and fund product development. In the U.K., British Aerospace is planning to dispose or significantly downsize four commuter and corporate aircraft divisions[65], while Shorts Brothers of Belfast was acquired by Bombardier in 1989, but only after a commitment by the U.K. Government to recapitalize it and write-off old debt.[66] In 1988 Bombardier acquired Canadair from the Canadian government, which covered some of the

65/ This follows the failure of the concern's US$ 734 million rights issue, in which only 4.9% of the shareholders wanted to buy new shares. See Air Transport World, December 1991, p. 116.

66/ Bombardier acquired Shorts Brothers in 1989 for 30 million pounds for the share capital. As a part of the agreement, the U.K. government was to inject 390 million pounds for recapitalization, write off a 390 million pounds loan it made to Shorts earlier in 1989, and offer 79 million pounds for capital investment to be spread out over four years. In exchange, Bombardier agreed to keep the Shorts name and refrain from selling it for four years. See Air Transport World, August 1989, p.88.

recurring costs for the post-acquisition development of the Canadair's regional jet RJ601.[67]

4.14 In Europe, Fokker, DASA, SAAB, Alenia and Aerospatiale, among others, have required Government funds to restructure their debts and help develop their commuter programs.[68] In North America, Canada's de Havilland, maker of the Dash series and acquired by Boeing in 1986 (for US$ 76.5 million cash and US$ 55 million deferred payments), reportedly accumulated losses anywhere from US$ 400 million to one billion from the time of acquisition to end 1991 (in mid 1990, it was reportedly losing US$700,000 on each Dash-8). Boeing was not able to turn it around, despite its strong managerial reputation, technical expertise and deep pockets. Boeing was finally able to sell de Havilland to Bombardier and the Province of Ontario in January 1992, after EEC officials rejected the bid from ATR on the basis that the resulting firm would have a 50% share of the commuter aircraft market and eliminate competition from new designs.[69]

67/ See Air Transport World, March 1989, p.95. Regarding the stretch version of the regional jet, Canadair chairman said that it would only be built with the help of the Canadian government. See Air Transport World, July 1991, p. 53.

68/ In 1987, for example, Fokker made a loss of US$ 53 million; the Dutch government was forced to come to rescue it by agreeing to lend or guarantee some US$ 400 million in development funds. Although the firm improved its position subsequently, it was under Government orders to find a partner. See The Economist, Sept 3, 1988, p.2. DASA of Germany, which is planning to lead the development of a new airframe and engine series for the 80-130 seat market, was requesting from the government subsidies of up to US$ 450 million for the aircraft's development. See Aviation Week and Space Technology, April 29, 1991, p. 52.

69/ Bombardier paid $51 million (Canadian) for a 51% stake in the new de Havilland; and the Ontario Government, $49 million for a 49% share. Of the $100 million in cash, 70% went to Boeing for de Havilland's assets and the remainder to fund operations of the new company, which will assume $190 million of the Boeing's de Havilland's liabilities. Thus Bombardier's total equity commitment was $147.9 million (Canadian) and the Ontario's $142.1 million. In addition, Ontario and Canada's national government will provide at least $490 million in financial support for the joint venture over five 5 years: $170 million over three years from the federal government to help the company restructure itself, and $20 million in each of the fourth and fifth years of operation, subject to approval of the firm's long-term strategic plan; $60 million through Canada's Defense Industry Productivity (DIPP) to support research and development, and diversification; and $200 million in loans over de Havilland's first three years of operations from the Province, as well as $60 million to match DIPP financing. See Aviation Week and Space Technology, January 27, 1992, p. 42.The government of Canada and of the province of Ontario provided, in addition, some Can $ 490 million support for the joint venture. See also Richard Baldwin and Harry Flam, "Strategic Trade Policies in the Market for 30-40 Commuter Aircraft," Institute for International Economic Studies, Seminar Paper 431, University of Stockholm, February 1989, Financial Times, June 26, 1991, Air Transport World, September 1990, p.190, February 1991, p. 140, May 1991, p. 99, and August 1991, p. 101.

4.15 Finally, in the U.S., Beech by end 1990 cut production on its 1900, King Air and other products, and planned significant layoffs.[70] Fairchild, owned by GMFI--Gene Morgan Financial Investment--filed for Chapter 11 bankruptcy protection in mid 1989 a few days after laying off nearly 400 employees. Yet in April 1990 it reached agreement with its lender (Sanwa Business Credit Corporation) that enabled it to emerge from bankruptcy and resume production of its Metro III series.[71]

4.16 In the case of Embraer, there are other reasons for its financial difficulties, in addition to an increasingly competitive market. Contrary to the 1970s and early 1980s, when the firm could count on a number of mechanisms to finance its activities, Embraer faces an extremely tight budget constraint. In the beginning, the company had to muster funds for facilities, tooling, assembly jigs and working capital to put the Bandeirante (and soon thereafter, the Ipanema) through serial production. Most (but not all) development costs had been already incurred by the Air Force at CTA, though further model development, an equally resource-intensive task, was undertaken at Embraer.

4.17 Initial funding came from the Government in form of two distinct contracts: one for 112 Xavantes and other for 80 Bandeirantes, both from the Air Force. After the mid 1970s, export sales grew sharply, and made an important contribution to Embraer's cash flow. In addition, a mechanism for the capitalization of Embraer was established, enabling tax paying corporations to set aside one percent of corporate income tax owned by companies in Brazil to be applied for the purchase of non-voting "preferential" stock in the company.[72] Through this mechanism, a total of US$ 305.8 million were infused into Embraer over the period 1970-85 (Tables 13A and 13B), over 16% of aggregate net sales for the period. In constant 1991 U.S. dollars, this would be equivalent to 493.5 million.[73] The relative importance of this mechanism in capital formation is evidenced by the fall in the Government's share in total equity (voting and nonvoting shares), which decreased to little over 5% in the early 1980s (though the Government still remained the controlling stockholder). Yet in the 1980s the Government was forced to expand its equity position in attempts to improve Embraer's balance sheet. As a result, by August 1990, the Government's ownership expanded to 88.1% of total shares.

70/ See Air Transport World, December 1990.

71/ See Air Transport World August 1989, p.91; June 1990, p. 221; August 1990, p. 102; and June 1991, p. 248.

72/ As a result, Embraer's preferential shares (that is, those with no voting rights), which consist of over 90 percent of the total stock, is privately owned by almost 200,000 private firms. Note that the incentive granted to Embraer competed against other fiscal incentives which corporations could opt -- for reforestation, tourism, and investments in the Northern and Northeastern region.

73/ The deflator used was the producers price index of the International Monetary Fund's International Financial Statistics.

Table 13A: EMBRAER -- FISCAL INCENTIVES INFLOW US$ million (current) 1970-1979									
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
0.3	5.1	7.7	10.3	15.9	21.1	21.4	28.7	29.4	26.4

Table 13B: EMBRAER -- FISCAL INCENTIVES INFLOW US$ million (current) 1980-1985						
1980	1981	1982	1983	1984	1985	Total (1970/85)
24.8	29.8	31.0	20.6	16.8	16.5	305.8

Source: R. Ramamurti, op.cit., Tables 2A and 2B, and Embraer.

4.18 In the initial years, a combination of Government orders, strong external sales and low-cost equity infusions were sufficient to ensure that Embraer's leverage remained within manageable limits. Long-term loans as a proportion of total assets oscillated between 0 and 4% in the period 1970-80. Yet the firm's attempt to develop a number of aircraft simultaneously in the 1980s, at a time of a major fiscal crisis in Brazil led to financial disarray.[74] Major programs (such as the Brasilia, starting in 1980) were financed through short-term loans, not a very prudent policy, to say the least. Not that Embraer's management failed to recognize the importance of changing its capital structure. Already the 1987 Annual Report, for example, called for "measures [t]o increase capital and improve the debt situation...as the only way to guarantee the equilibrium required for the continuity of new programs..." Yet despite such calls for balance sheet restructuring, and the limited action in this respect, Embraer continued to push its programs forward.

4.19 Embraer's strategy of taking on short-term loans to carry out its development work was extremely risky and proved itself ultimately disastrous to the company. In this regard, it is noteworthy that whereas in the 1970s most of Embraer's development costs associated with the Bandeirantes, the Ipanema, the Xavantes where absorbed by the Air Force, the same did not happen

---

74/ To the financial community, Embraer's crisis was due to "combination of bad luck, punishing Government policies, overambition and lack of foresight by management, all compounded by the recent difficulties of obtaining financing" -- See Wall Street Journal, Nov 13, 1990. According to the Bank of America, which in 1989 took a 5% stake in Embraer through a debt-for-equity swap, the main cause for the crisis is that Embraer had to finance their development program without an adequate capital base.

in the following decade (Table 14). Then, Embraer had to undertake on its own three major projects: the Brasilia, the Vector and the regional jet (EMB-145). Yet just as profits from the Bandeirante were insufficient to finance the Brasilia in the early 1980s without Embraer taking on a large debt for the first time in its history, income from the Brasilia (and the Tucano) was too small to fund development programs when the Government phased out its indirect support of the firm, starting in the early 1980s.

Table 14: DEVELOPMENT PARAMETERS OF EMBRAER'S PROGRAMS

Aircraft	Costs a/ (in US$ m)	Finance b/	Years c/	Period
Bandeirante	NA	AF	3	1965 - October 1968
Ipanema	NA	MAg	3	1968 - July 1970
Xingu	80	EMB	2	1974 - October
AMX	200	Af	5	1980 - October
Tucano	6.5	AF	2	1979 - August
Brasilia	250	EMB	3	1980 - July 1983
CBA 123	210 d/	EMB	4.5	1986 - July 1990
EMB 145	>50	EMB	--	1989 -

Sources: Embraer, R. Ramamurti, op.cit., p. 194-5, and various publications.

Notes:

a/ Approximate development costs in current US$;

b/ Basic source of finance: AF, the Brazilian Air Force; MAg, Ministry of Agriculture; EMB, Embraer;

c/ Time elapsed between development go-ahead decision and first prototype maiden flight;

d/ The 123 development and initial production tooling and assembly jigs (including 4 prototypes) cost Embraer an estimated US$ 210 million (with an additional US$ 70 million for Fama); to put the plane into serial production would require another US$ 60 million from Embraer (US$ 20 million from Fama).

4.20 After the substantial development efforts of the last 12 or so years, the key financial problem that Embraer faces is how to reduce and transform the term structure of its debt, that at end 1991 stood at US$ 1,152 million, including US$ 549 million of short and medium-term (Table 15). In 1989, the last year that Embraer was profitable, it was able to raise US$ 185 million by issuing US$ 85 million in convertible debentures in the domestic market and US$ 100 million through a conversion of commercial bank-held foreign debt into equity (non-voting shares). In 1990, its plans were to raise another US$ 150 million through debt conversion and US$ 50 million of commercial papers in the European market, neither of which were carried out, as the Government refused to release funds from the already authorized debt conversion scheme.[75] Embraer was owed by end 1990 US$140 million from the Brazilian Government, US$ 30 million by Egypt and the remainder by Honduras (the last two debts related to Tucano sales of aircraft or disassembled kits). In addition to sharply falling sales during that year, the Air Force reduced its annual purchase order from 15 to 8. As a result, in October 1990 Embraer laid off 3,994 or 32% of its work force. Its total losses for the year were US$ 265 million[76].

Table 15: EMBRAER END-YEAR POSITION FOR KEY INDICATORS

	1970	1975	1980	1985	1986	1987	1988	1989	1990	1991 b/
Net sales	7	79.2	171	219	378	473	330		573 a/	417
Net Income	(0.2)	7.5	(4.9)	(5)	10	13	(35)	89	(265)	(88)
Aircraft Delivery c/	0	68	103			213	138	211	128	79
Net asset				98	1453	158	178	416	126	35
Liabilities				297	367	541	649	729	964	1112
LT						29	61	132	119	563
Current						504	588	597	848	549

a/ 48% Brasilia; 25% AMX; 8% spare parts; 6% Tucano; 5% Bandeirante; 5% light aircraft; 3% others; b/November 1991; c/excluding the Ipanema and the Piper line.

Source: Embraer

4.21 In mid 1991, Embraer's financial position became unsustainable, despite the company being credited US$ 250 million the Government owed in accounts payable. The Government attempted to partially overcome the crisis by changing Embraer's debt structure, with a US$ 407 million loan disbursed in two tranches, with repayment scheduled over 5-7 years. Also included in the package is unlimited export financing for the Brasilia. Yet that did not go far enough in changing the fundamentals: at the end of November 1991, there was still a very large short-term debt (nearly US$ 550 million), reduction in sales continued unabated (the number of aircraft sold, which in 1990 had already decreased substantially from the previous year, contracted further to just 79), and losses for the year (eleven months) were nearly US$ 90 million.

4.22 Moreover, a number of additional critical issues remain unresolved. Not only short-term but also the total debt size is still too large

---

75/ See The Financial Times, June 27, 1991.

76/ Of the 1990 losses, an estimated US$ 165 million was due to aircraft delivery delays required by customers, and US$ 65 million due to options not turned into firm sales. See Air Transport World, December 1990.

for the firm's capital base; an equity infusion seems inevitable if Embraer is to survive either as a public or private enterprise. In addition, Embraer still faces the quandary that led it to its state of financial disarray: how to develop and market new, competitive products in order to stay at the industry's forefront, without putting in jeopardy the firm's future? The CBA 123 remains at the prototype stage; it will take 50-100 orders before Embraer is able to "ride down" the learning curve and compress its costs sufficiently to become competitive. Embraer might have, therefore, to absorb substantial losses in the initial sales efforts as an additional "investment" in the 123 to ensure that costs come down significantly (unless the Governments of Brazil and Argentina were willing to place a substantial order). For the EMB-145 regional jet the issue is more complex: in its rescue plan, the Government stipulated that the company would have to find a partner to develop and produce the new aircraft, with Embraer investing US$100 million and an additional US$ 350 million from a foreign company.[77] Clearly, in view of the current circumstances in the aviation industry, it might not be easy to find such a partner. However, the need for partnership and cooperation is clear, and this trend is being observed worldwide.

B. Cooperation and Other Cost-Minimizing Strategies in the Commuter Aircraft Market

4.23 In the new environment of growing development costs, intensifying competition and financial difficulties, firms are under strong incentive to find partners, establish alliances, and share risks (see Table 16 and the more detailed Annex Table 1). Thus, while producers attempt to expand their international marketing efforts and sales, there is a parallel movement towards the globalization of the industry with a search for allies that can undertake joint development, establish co-production arrangements, and cooperate in commercialization of aircraft. In addition, the extent of international subcontracting is increasing. These trends are observed among producers of both commuter and larger aircraft, as well as engines.[78]

4.24 Table 16 confirms the trend for prime contractors to employ a growing number of development/manufacturing partners in last-generation commuter aircraft programs (such as Dornier 328 and SAAB 2000). It is also striking how Embraer failed to find effective risk-sharing partners for its two major programs developed in the 1980s. In case of the EMB-120, Embraer basically did it alone, despite the adverse impact on its debt levels and term structure. For the CBA-123, the Argentine partner (FAMA) was unprepared to take on the complex job. It is likely that lack of proper project supervision by Embraer on its partner's building sit caught Embraer by surprise when FAMA wasn't able to deliver, and had to lower its work share to 20%.

77/ See the Financial Times, "Brazil Approves Embraer Rescue," July 2, 1991.

78/ See, for example, Joan Feldman, "Development Strategies for the World Airlines," Economist Intelligence Unit Special Report No. 1133, September 1988.

Table 16: INTERNATIONAL COOPERATION IN THE COMMUTER AIRCRAFT INDUSTRY a/
Prime Designers and Contractors

Aircraft	A	B	C	D	E	F	G	H	I	J	K	L	M	N
CBA-123 b/											X		X	
EMB-120											X			
Dash-8	X	X			X									
SAAB-340 c/	X							X						
CN-235 d/						X				X				
N-250										X				
ATR-42 e/			X				X							
Dornier 328 f/		X		X			X					X		
ATR-72			X				X							
F-100 g/		X		X					X					
BAe-146	X	X						X				X		
SAAB2000 h/		X				X		X						X
ATR-92			X			X	X							

Source: Aircraft producers and various publications.

Note:

a/ A--US; B--UK; C--France; D--Germany; E--Canada; F--Spain; G--Italy; H--Sweden; I--Netherlands; J--Indonesia; K--Brazil; L--S.Korea; M--Argentina; N--Finland.

b/ Argentina designs and manufactures major fuselage parts (20% of work share, down from 33%);

c/ Partnership between Fairchild and SAAB ended in failure, setting the 340 program back by a few months;

d/ The work share is approximately 50-50, with IPTN designing and manufacturing outer wing sections, rear fuselage, complete tail and interior, while CASA is responsible for the inner wing sections, forward fuselage, center wing and engine nacelles;

e/ Italy's Alenia (formed by Aeritalia and Selenia) designs and produces fuselage and tail units; France's Aerospatiale designs and manufactures wings;

f/ Daewoo Heavy Industries produces the fuselage shells (25% of work share), Aermacchi Varese develops and produces cockpit shells and assembles fuselages (10% work share), and Westland Aerospace produces engine nacelles (4% work share);

g/ Short Bros. builds the wings; Deutsch Aerospace the fuselage.

h/ CASA designs and manufactures the SAAB 2000 wing (as scaled up version of the 340 wing); Valmet of Finland produces the fin, rudder, horizontal stabilizer and elevator; and Westland manufactures the rear fuselage.

4.25 In addition to share development and other costs, firms attempt to minimize them by exploiting with growing frequency the "family" concept of developing "stretch," more powerful, longer range or higher performance versions of existing aircraft. The idea behind this production strategy is to maximize communality between operating and to-be-developed aircraft. Efficient "in-family" design is capable of cutting development costs substantially.[79] The approach also helps defray setup-related expenses by using common tools and assembly jigs. As a result, the number of commuter aircraft families is growing (Table 17 and Annex Table 2).

Table 17: COMMUTER AIRCRAFT FAMILIES a/				
		Family b/		
Producer	Parent	Generation 1	Generation 2	Generation 3
Embraer	EMB-120	CBA-123	EMB-120ER	EMB-145
ATR	ATR-42	ATR-72	ATR-82	ATR-92
DeHavilland	Dash-8-100	8-300	8-400	
Dornier	228	328	328S	
Beech	1900	1900C	1900D	
IPTN	NC-212	CN-235	N-250	
Fairchild	Metro III	Metro 23	Metro 25	
SAAB	340	340B	2000	340C
Fokker	F-28/4000	F-50	F-100	F-80/F-130
BAe	Jetstream 31	Jetstream 41		

Source: Various Publications

Notes:

a/ The extent of communality varies substantially: some aircraft may be upgrades, others quite different models; b: not all members of the family are included.

4.26 As discussed above (Chapter III), Embraer has used the family concept both in its development of the CBA-123 and in the conceptualization and design of the EMB-145 regional jet. However, the extent to which Embraer was willing to use existing structures and systems to build on new versions was insufficient to lower development costs to levels consistent with its financial capabilities. The complexity of the decision of how to build up a family should not be underestimated, however. Take the case of the EMB-145. Embraer faced two fundamental questions. First, whether to stretch and offer a version of the Brasilia with greater seat capacity. The need for larger commuter lines seem clear in the U.S. commuter market. Average number of seats per aircraft increased from 11.9 in 1978 to 21.8 in 1989, at an annual

79/ The development costs of the Dornier 328S, a 48-passenger stretch version of the 328, to be delivered in 1996, is expected to be half of the 328, in view of the high degree of communality of the two aircraft. See Air Transport World, December 1991.

compound growth rate of 5.6.[80] Thus the decision to "stretch" the Brasilia seemed corrected on a prima facie basis.

4.27 The second basic question Embraer faced in introducing a stretch version of the Brasilia, was whether to make it a turboprop or a regional jet. It is still unclear why Embraer chose the jet option, although the prestige associated with designing and producing a pure jet may have to do with the decision. In any case, there were other factors weighing, the main one being a perceived market trend towards jets in commuter routes. The regional jet is principally designed for longer regional routes and the aircraft is ideal for hub bypassing--increasing the network of airports that can be reached. The question for many feeders is: should they concentrate on short-haul feeding or increase the radius, and progressively move to serve city-pairs? There is significant uncertainty in the market, and operators are hedging[81].

4.28 Upgrading of existing aircraft may be considered a limit case of a production strategy centered in "designing within the family," and with maximal communality. Although development and setup costs are minimized as a result, this course of action only makes economic sense if there is a reasonable probability that the orders for the upgraded model will provide a sufficient high return, and conversely, that without its upgradation, the market share for the old model would dissipate. Clearly, Embraer did not employ such a decision rule when deciding to develop the CBA-123, in response to the Bandeirante's weakening market position. As described in Chapter II, the aircraft is radically different from the Bandeirante (which it purports to substitute), and although sharing with the EMB-120 some common parts of the fuselage, it provides a far superior performance yet at a relatively steep per-seat price.

4.29 In contrast, other producers have attempted to maintain market share on the basis of upgraded models, as with of Beech Air, which followed the 1900C, and subsequently with the new 1900D: the latter costs approximately US$ 3.95 million (US$ 500,000 more than the 1900C), and despite being still within the US$ 200,000 per seat threshold, has found some difficult being marketed.[82] Not only Beech, but also Fairchild's strategy is one of step-by-

---

80/ According to the U.S. Regional Airline Association Annual Survey, 1989, and AvStat Associates.

81/ SkyWest Airlines, for example, a Delta regional feeder, placed orders for 20 SAAB 2000s while maintaining its existing 10 options on Canadair RJ. Still, the mainstay of this operator's fleet will be the Brasilia. In 1989, SkyWest had 6 EMB-120s, and was supposed to take delivery of 5 in 1991, 10 in 1992 (incl. 4 options). Then it had further four options in 1993 and 1994. The EMB-120 is supposed to replace the 19-passenger Metro III as these aircraft come off lease, an additional piece of evidence of commuterliners' trend towards larger aircraft.

82/ Mesa airline was the lauch customer of the 1900D, after signing a letter of intent for 25 aircraft. The aircraft was certified in 1991; it is not high performance -- cruising speed, for example, is 280kt -- but appears adequate for the market requirements. Price, however, is considered a problem, and in mid-1991, Mesa had yet to decide to place firm orders.

step improvements, as evidenced from its transition of the 19-passenger Metro III to the 23C. Matching the 1900D, Fairchild is pricing its new model also in the vicinity of US$ 4.0 million.[83]

4.30 Not that producers are not considering entering the 19-passenger market with high-performance versions. Yet, they are being cautious. In mid-1989 Dornier was examining the possibility of a technologically advanced successor for its 228 (much like the CBA 123 in basic characteristics), a tacit signal by the German manufacturer that the 19-seat market may continue into the next century, despite a trend towards larger aircraft. In view of the price-related market acceptance problems of the CBA-123, it is unlikely that Dornier will develop its new plane unless able to price it in the US$ 4 million range.[84]

4.31 Finally, the movement towards cooperation among producers, and the emphasis on product "families" and improved versions, may also be regarded as a response to a key strategic issue facing aircraft manufacturers, namely, how to broaden the scope of their product line without undue financial stress.[85] With too narrow a line, they may not be able to compete insofar as customers prefer to move up the capacity/performance gradient with the same manufactures to save on training, spares and transaction costs. Yet to widen the scope of production and undertake development of a number of new products might put in jeopardy the financial health of the enterprise, as suggested by Embraer and other cases. Thus, in addition to search for international partners and investigate the possibility of stretching/modifying versions of current products, aircraft producers are also considering acquisitions as a cost-minimizing alternative to remain competitive and profitable in a market that is highly likely to undergo major structural changes in the coming years.[86]

See Air Transport World, August 1990 and May 1991.

83/ A rough estimate of the price of this aircraft can be inferred from the Aeromexico order of 27 Metro IIIs and 23s for over US$ 100 million, close to US$ 4 million per plane. See Air Transport World, April 1991.

84/ Dornier's own market analysis predicts a demand of over 100 15-19 seat turboprop after the year 2000. Yet, according to Dornier's president, a factor in the decision would be the market acceptance of Embraer's CBA 123. See Air Transport World, August 1989.

85/ In case of Embraer, the rationale for undertaking the EMB-123 program and starting the 145 with no real partners to speak of was that Embraer couldn't wait, to the extent that "the regional airline market has a relentless demand for advanced products, and Embraer will at a disadvantage without those two aircraft [the EMB 123 and 145]." See "Embraer Slows Program Development While Reviewing Commuter Market," in Aviation Week and Space Technology, Nov. 11, 1991, p. 53.

86/ ATR's 1991 bid for de Havilland, for example, appears to have been an attempt to offer a "wider" line of products, bypassing large development costs associated with the introduction of new designs to satisfy customer's requirements of aircraft of different seat capacity. Though

4.32 The current circumstances of excess supply of aircraft and models is unsustainable and will in all probability lead to mergers, acquisitions, and exit of producers.[87] By the end of the decade, far fewer producers will remain, and those that do will be competing with a broader array of models, and with significant communality among them. Clusters of allied producers will be competing head-on, and the extent of product "overlap" will be substantial. The niche markets of the late 1970s and early 1980s will have disappeared.

---

the bid was rejected on antitrust grounds, ATR's motive appear quite sound to strengthen its competitive position.

87/ A recent report is suggestive of the trend. It states that "on May 18th Deutsche Aerospace said that, along with Aerospatiale of France and Alenia of Italy, it was negotiating to take control of Fokker...Most of Europe's aircraft makers want to build a new generation of small jet airliners for use on short-haul routes, but they lack the money to do so. So they are keen to spread the risks (and any government subsidies) around. Deutsch Aerospace has been planning a new consortium called Regioliner. Together with Aerospatiale and Alenia, it aims to produce a 120-seater jet in 1996. This would cost about US$ 2.5 billion to put into production and all three firms have been hoping for government cash to help it get off the ground...Fokker already makes a successful 100-seat jet, which it planned to alter to produce an entire family of small jets. This would be much cheaper than building a new jet from scratch, as Deutsch Aerospace wanted to do. If the deal goes ahead, Regioliner will be shelved. Deutsch Aerospace already builds the fuselage of Fokker's jet, but it wants to be boss, not just a supplier. It proposes to take a 26% stake in Fokker, while the French and Italian companies take 12.5% each." See The Economist, May 23rd 1992.

V. CONCLUDING REMARKS: IMPLICATIONS FOR INDUSTRIALIZING COUNTRIES

5.01 The commuter aircraft industry has undergone major changes in the last decade or so. Both technological and market forces have converged to make the survival of incumbent firms more difficult. On the one hand, increased aircraft size and complexity have led to an escalation of development costs; on the other, the market has become more crowded, with a greater degree of product overlap. At the same time, firms are being pushed to develop and offer not one, but families of aircraft characterized by substantial communality to enable a reduction in users' operational costs. As a result, producers are under competitive stress and many have posted losses. Those linked to or in any way supported by Government funds are claiming large infusions of capital to sustain their market position.

5.02 Industrializing countries which have nurtured sophisticated industries that have accumulated significant technological and other capabilities, such as aircraft, are facing a difficult predicament. A fast-moving frontier will make many of their technical endowments obsolete; upgrading them will require growing commitment of resources at the same time that an increasingly competitive market dissipates the profits that could be retained to finance such investment.

5.03 To approach this quandary, industrializing country firms must first find partners. This is even more imperative than for developed country producers with greater access to financial resources. Here flexibility is key. Within a well-articulated, long-term strategy, they should be willing to share development projects (despite the potential prestige of "doing it alone"), enter co-production arrangements to minimize costs and risks, integrate product lines at the commercialization and post-sale stage, and subcontract in and out to the extent of their capabilities. Increased cooperation will stimulate firms to specialize and share tasks according to their relative strength and resource constraints.

5.04 Second, temporary support may be required as firms restructure their operations. Such support--in the form of restructuring finance, switchover or exit subsidies, for example--must however be contingent on a credible commitment by the producer to reduce costs, increase revenues, search for partners, all within a given horizon (say 1-2 years). Any permanent support must be justified on the basis of substantial spillover effects. The externalities would need to be large and identifiable. The potentially positive impact of an industry on labor training and the acquisition of skills, the development of a subcontractor network, and the development of a growth pole of efficient firms producing high value-added products are examples of such externalities.

5.05 It is not easy to quantify spillover effects, and much less to come to a judgement whether the direct and indirect resource costs of an operation such as aircraft development and production are economically justifiable. Embraer, for example, has had an important role in improving labor skills through in-house and on-the-job training. Although since its inception, Embraer could draw from a pool of available qualified aeronautical engineers trained at ITA (the Air Force engineering school), it did not have similar access to technicians and skilled workers.[88] Operators, programmers and specialists for numerically controlled machining centers were particularly scarce; there was also a dearth of personnel for assembling operations, both structural and final, and in the area of composites. As a result, Embraer had to invest considerable resources in training. To illustrate the magnitude of the effort, during 1989 Embraer Training Center averaged two courses per employee (for a total of nearly 25,000 training units).

5.06 Although such in-house and on-the-job training provide a positive externality, its magnitude is not well defined. Training in aircraft production is often focussed on skills that are quite industry-specific, where the industry, in the case of industrializing (and many other) countries, is generally constituted by a single firm. What is learned is therefore not as easily transferable as when many firms populate an industry. There may be in fact a net welfare loss for the country if more productive use for these labor resources could be found in other activities. By absorbing the best engineers and technicians, people in relatively scarce supply in the country, the producer could be precluding their alternative use.[89]

5.07 The presence of significant backward linkages in terms of the development of subcontracting relationships provides an additional external dimension of industrial activity. A high percentage of the value of the airplanes produced by Embraer is of Brazilian origin (from 40-80%, depending on the aircraft). In part, this results from the high labor share in the value of an airplane, which varies between 30 and 50 percent of its total cost. In part, this is the outcome of a moderate degree of vertical integration[90] and an emphasis on horizontalization through subcontracting and supplier development.

5.08 Yet aircraft, different from high-volume industries such as automobiles, require small quantities of many parts and components, all produced under tight tolerances and strict standards. This conspires against the development of an aircraft parts industry in a country where there is basically one single moderate-sized producer. Though over 300 suppliers located themselves "around" Embraer, and the development of their technological capabilities, with a special focus on quality improvement, has

---

88/ For ITA engineers, which are among the best-trained in Brazil, Embraer's positions have traditionally been regarded as quite desirable.

89/ This would be the case if the company pays labor above its marginal productivity; or if barriers to labor mobility precludes an effective response to wage differentials.

90/ Embraer produces, among other items, landing gears and pylons for the EMB-312 Tucano, as well as wheels, brakes and several hydraulic system components for the AMX aircraft.

been an explicit objective of Embraer since then,[91] one would be hard pressed to argue that the development of Embraer's supplier network has been an externality which might justify the resources absorbed by the enterprise.

5.09 The kind of spillover that might offer such a justification is one that is much more difficult to assess: its impact is long-term and the relationship with a firm such as Embraer, more diffused. It is the growth of an important industrial pole of skill-intensive and sophisticated industries in the region. In this regard, Embraer's labor training and supplier development efforts have been of significance, particularly in the sense that they have been instrumental in creating an industrial culture in the Sao Jose dos Campos region consistent with the complex tasks and exacting standards that characterize an aircraft industry. It may be in this latter and less quantifiable sense that Embraer has had the greatest external impact on the region.

5.10 It should not be forgotten, however, that prior to Embraer, the Sao Jose area was already a center of excellence in higher technical education and research, and spinoffs from the CTA complex had started a few years before Embraer's creation. No doubt Embraer's contribution to the development and consolidation of the Sao Jose industrial growth pole was significant though not easily quantifiable. Still, Sao Jose's preeminence as a "high technology" pole was fundamentally due to the presence of the CTA teaching-research complex and its strong commitment to provide industry the technological means for development. In this sense, the largest externalities from firms such as Embraer are reaped when they are not isolated clusters of industrial activity, but the offspring of prior investments in education and applied research (as well as in critical physical infrastructure such as telecommunications). Resource allocation decisions should reflect this reality.

91/ For the AMX program, for example, a number of suppliers were brought in, including Celma, for the production of 30% of the parts licensed by Rolls Royce, and the final assembly of the engines; Aeromot/Aeroeletronica; ABC Sistemas Avionicos e Simuladores; Engetronica; Microlab; Elebra and Tecnasa.

ANNEX TABLE 1

REGIONAL AIRCRAFT MANUFACTURERS/RISK SHARING ALLIANCES

AIRCRAFT MODEL	PROPELLERS			AVIONICS		POWERPLANT						REGIONAL AIRCRAFT MANUFACTURERS																OTHER MANUFACTURERS							
	HARTZELL (USA)	HAMILTON STANDARD (USA)	DOWTY PROPELLERS (UK)	HONEYWELL PRIMUS (USA)	COLLINS AVIONICS (USA)	ROLLS ROYCE (ENGLAND)	GARRETT (USA)	TEXTRON LYCOMING (USA)	GM/ALYSON (USA)	GE (USA)	PRATT & WITHNEY (USA	AEROSPATIALE (FRANCE)	ALENIA (ITALY)	BEECH (USA)	BRITISH AEROSPACE (ENGLAND)	CANADAIR (CANADA)	CASA (SPAIN)	DE HAVILLAND (CANADA)	DEUTSCHE AEROSPACE (GERMANY)	EMBRAER (BRAZIL)	FAIRCHILD (USA)	FOKKER (NETHERLANDS)	IPTN (INDONESIA)	SAAB (SWEDEN)	SHORT BROTHERS (N. IRELAND)	CZECHOSLOVAKIA AEROSPACE	FAMA (ARGENTINA)	HARBIN PLANT/OTHER (CHINA)	TEXTRON AEROSTRUCTURES (USA)	DAEWOO HEAVY INDUSTRIES (KOREA)	VALMET FLYGSPAN (FINLAND)	SUNDSTRAND (SWEDEN)	AIM AVIATION (ENGLAND)	AERMACCHI VARESE (ITALY)	WESTLAND AEROSPACE (ENGLAND)
ATR 42/72 (1)		X			X						X	○	○															△							
BAE ATP (2)															■													△							
BAE 146 (2)				X				X							■									△				△	●						
CBA-123	X						X													○							○								
BRASILIA		X									X									■															
CANADAIR (3)					X					X						■									●										
DASH 8		X									X							■										△							
DORNIER 328 (4)	X			X							X								■											●				●	●
FOKKER 50			X								X											■													
FOKKER 100 (5)			X			X													●			■	△		●										
LET 610 (6)					X					X							●									■									
MPC 75 (7)												○	○						○																
NC 212 (8)			X				X										●						▭												
CN 235 (8)	X									X							○						○												
SAAB 340 (9)			X		X					X											○			■											
SAAB 2000 (10)		X	X		X				X								●							■							●	●	●		●
SHORTS 360 (11)																									■			△							

LEGEND:

RISK SHARING MODALITIES

- ○ Joint venture (Co-development and co-production)
- X Traditional subcontracting: powerplant, avionics, propellers
- ■ Main producer
- ● Subcontracting in significant portions of aircraft as fuselage portions, wings, wing portions, etc.
- △ Subcontracting in minor portions of aircrafts as doors, wing components, tail components, etc.
- ▭ Licensing of aircraft manufacture

Please see next page for notes for the table

NOTES ON ANNEX TABLE 1

1. Aerospatiale (France) and Alenia (Italy) formed the ATR Consortium in a 50/50 association for the development and manufacture of regional aircraft (co-design and co-produce). Aircraft components are manufactured at different plants located in the two countries: Fuselage and tail units are assembled in Italy; outer wing boxes are produced in France and mated with the central wing in France. Final aircraft assembly takes place in France. The consortium builds the ATR 42 and the ATR 72 aircraft. A factory in Xiang (China) is building parts for the ATR 42 (see David McKendrick, "Acquiring Technological Capabilities: Aircraft and Commercial Banking in Indonesia," University of California, Berkeley, Nov. 89, pg. 67.

2. British Aerospace has cooperative programs with several Asian companies. These include subcontract production of BAe 146 landing gear and access doors and ATP ruders at plants in Harbin and Shenyang (China) respectively (see Air Transport World, September 3, 1990). BAe avionics are manufactured by Honeywell (USA); engines by Textron Lycoming (USA) and wings by Textron Aerostructures (USA) (see Air Transport World, September 1991, pg. 117). A few parts for the BAe 146 are manufactured by Saab (see Air Transport World, December 1990, pg. 97).

3. Canadair RJ center fuselage is designed and manufactured by Short Brothers, which is also developing the tooling. Short is also designing and building the spoilers, flaps and other "feathers" of the RJ wings (see Air Transport World, September 1990, pg. 193).

4. Deutsche Aerospace subcontractors for the Dornier 328 are: Daewoo Heavy Industries (Korea) which builds the fuselage shells (25% of the work); Aermacchi Varese (Italy) is responsible for the development and production of the cockpit shell and for assembling the fuselage (10%); Westland Aerospace (UK) produces the engine naceles (4%) and Dornier is responsible for the rear fuselage, empenage and wing and for systems integration and final assembly (see Air Transport World, December 1991, pg. 83).

5. Dowty (UK) builds the undercarriage, Rolls-Royce supplies the engines and Short Brothers (Northern Ireland) makes the wings for the Fokker 100 (see The Economist, September 3, 1988, pg. 6). Deutsch Aerospace builds the fuselage (The Economist, May 23, 1992, pg. 72). IPTN supplies wing and tail components (see David McKendrick, op. cit., Table 2.7).

6. There is a recent preliminary agreement between LET, CASA and GE by which the entire CASA CN 235 propulsion system will be adapted to the LET 610. Under this agreement CASA will supply the composite cowlings and all other Spanish manufactured hardware directly to LET (see Air Transport World, December 1990, pg. 110).

7. In 1986 the MPC was launched in Beijing with the signing of a Memorandum of Understanding on a 2-year feasibility study between MBB (Germany) and the Chinese National Aerotechnology Import and Export (CATIC). In 1990, the program was probably going to continue but without the participation of CATIC, which owned 20% of the MPC company (see Air Transport World, June 1990, pg. 220). In 1991, Aerospatisale and Alenia were planning to form a new European jet firm with DASA (Deutsche Aerospace) for the development and manufacture of regional aircraft (25/25/50 association) to manufacture at least 3 types of jets, two models derived from the MPC-75, one with 80-90 seats and one with 120-130 seats (see Air Transport World, February 1991, pg. 140).

8. The NC 212 is being built by IPTN under CASA's license. P.T. Aircraft Technology Industries (Airtech) is a company formed on a 50/50 basis by CASA-Construcciones Aeronauticas of Spain and IPTN of Indonesia. The company was formed to co-design and co-produce the CN 235. Parallel assembly lines were set up in the two countries IPTN designs and produces the outerwing sections, rear fuselage, complete tail and interior in Indonesia and CASA designs and fabricates the more complex inner wing sections, forward fuselage, center wing and engine naceles. These components are exchanged and assembled in independent production lines in Spain and Indonesia (see David McKendrick, op. cit., pg. 42).

9. The wing and other parts of the Saab 340 were designed and manufactured by Fairchild. Originally there was a 50/50 association for the development and production of the aircraft. However, due to financial problems Fairchild abandoned the project (see David Mowerey, Alliance Politics and Economics--Multinational Joint Ventures in Commercial Aircraft, Ballinger Publishing Co., 1987, pg. 87).

10. Subcontractors for the Saab 2000 are: CASA (Spain) which designed the complete wing and manufactures it; Valmet Fygsplaindustri (Finland) which produces tail sections (fin, rudder, horizontal stabilizer and elevator); Westland Helicopters (England) which is manufacturing the rear fuselage; Dowty Aerospace (UK) which is responsible for the propeller system and Alison GMA for the engine and naceles. Sundstrand is making the air unit and optional auxiliary power unit. Rockwell Collins (USA) is responsible for the avionics and Hamilton Standard for the environmental control systems. Final interior completion will be done by AIM aviation (England) which is responsible for designing, manufacturing and installing all the interiors. Saab is responsible for the main fuselage and cockpit portion (see Air Transport World, Dec. 1990, pp. 92-93).

11. A plant in Harbin (China) makes doors and wing parts for the Shorts 360 (see David McKendrick, op. cit., pg. 67).

Annex Table 2: REGIONAL AIRCRAFT FAMILIES

Basic model/service date	Family members/service date	Description
Manufacturer: ATR Consortium (Aeritalia & Alenia)		
ATR 42: Dec. 85	ATR 72: Feb. 90	Stretched version of the ATR42 turboprop keeping same philosophy of simplifying concepts to obtain lower structural weight. First aircraft to be built with carbon outerwings resulting in a 20-30% reduction in weight. Passenger capacity increased from 42-50 to 64-74 seats.
	ATR 42-320: Feb. 90	"Hot & high" version of the 42 model . Same seat configuration.
	Super ATR 72	Same ATR72 equipped with a more powerful engine (300 kt) Offered by ATR in 1990.
	ATR 82	Stretched version. Basically the same speed of the ATR 72, plus 3 more rows of seats. Under consideration in 1990.
	ATR 56	A 56 variant of the family in consideration by ATR in Jan.92 Deliveries to begin in 1994.
	ART 92	A 90-100 seat super stretched variant. In the conceptual stage. To be launched in 1995.
Manufacturer: Beech Aircraft (USA)		
Beech 99: 68-78	Beech C99: 1981	Modified version of the original 99.
Beech 200/300 King Air: NA	Beech 350: Sept. 91	Stretched version (8-15 pass.) of the King Air 300: 34 in. in cabin length forward and aft wing. Increased wingspan and composite winglets. More room, same performance and economics. Extremely low cabin noise.
	Beech 1330: 1989	Enhanced 13 seat derivative of the King Air corporate aircraft. Fuel weight 11.000 lbs. Cruise speed 265 kt.
Beech 1900: Feb. 84	Beech 1900D: Dec. 91	Stand up cabin ; increased cabin height (14 in taller than the 1900C), adding 142 cu ft to overall cabin volume (28% increase).Cruise speed of 280 kt.
Manufacturer: British Aerospace		
BAe 146-100: May 83	BAe-200: Jun. 83 BAe-300: Dec. 83	The BAe 146 is a series of jetliners with passenger versions from 70 to 122 seats. Advanced wing design, short field capability and "hot and high" performance.
	RJ70: 3rd. Q/93	Basically the same 85 ft fuselage in overall length and 86 ft in wing-pan of the 146-100; carrying less fuel and with derated engines; shorter range than the 146 (800 mi X 1,300 mi). Introduced in 1990.

Annex Table 2: REGIONAL AIRCRAFT FAMILIES

Basic model/service date	Family members/service date	Description
	NRA	New Regional Airliner, 139 seat twin jet conversion of BAe 146. Deliveries to begin in 1996.
Jetstream 31 Dec. 82	Jetstream 41 1992	Stand up cabin (29 seat) stretched version of the Model 31 (19 seat) turboprop with re-designed wing and empennage. Enhanced fuselage (16 ft. stretch forward and aft wing). Additional 48 cu ft of stowage.
ATP: May 88		Advanced turboprop with 70 seat capacity.
Manufacturer: Canadair/Bombardier (Canada)		
CL 601, NA	Canadair RJ: Fall 92	Stretched (50 seat) version of the Challenger business jet, rolled out in 1991.Considerably longer fuselage (forward extension of 128 in and aft extension of 122 in.). Interior based directly on that of the business jet. Six ft and 1 1/2 in cabin length and 8 ft of cabin width. In 1991 plans were to certify two versions of the RJ: the standard 100 with range of 844 n.m. and the series ER (Etended Range) with range of 1.418 n.m.
	Canadair RJ-70	A stretched 70 seat version program will be explored by Canadair (1991).
Manufacturer: IPTN (Indonesia)		
CN 212: 1974		Multi purpose light turboprop designed to carry 19-28 passengers. Originally produced by CASA of Spain. Manufactured by IPTN under license.
CN 235: Dec. 88		Aircraft is a 35-44 turboprop co-designed and co-produced in parallel assembly lines in Indonesia and Spain. Designed for quick reconfiguration. Monowing configuration. Innovative feature is a wide ramp gate for cargo load.
N 250		The aircraft is a 50 seat twin turboprop wholly designed by IPTN without CASA's participation. Design was finalized in 1990. Aircraft will have the same fuselage tube as the CN 235 with a new cockpit and fully rounded fuselage belly. Roll out planned for 1994.
N 270		Work on a stretched version of the N-250 (carrying 60-70 passengers) and tentatively designated N 270 will start after N250 certification.

Annex Table 2: REGIONAL AIRCRAFT FAMILIES

Basic model/service date	Family members/service date	Description
Manufacturer: De Havilland (Canada)		
Twin Otter 1965		Aircraft is a 19 seat turboprop originally designed as an utilitary airplane.
Dash 7: 1975		Pioneer of the Dash family, is a 50 seat turboprop.
Dash 8 - 100 Dec. 84	Dash 8 - 300 Feb. 89	Stretched version of the 37-40 seat Dash8-100.Two fuselage extensions added fore and aft wing. Wingspan was increased and engines uprated. Landing gear beefed up to handle 6,600 lb increase in gross weight. 40% increase in passenger capacity (50-56 seats). 85% interchangeable line replacement units.
	Dash 8-100A Dash 8-300A: 1990	Improved models were to be certified in the Summer 1990. Both aircraft to have beefed up wings to handle the increased gross weight and meet the European certification standards. Larger bins with 70% more storage capacity; new recessed overhead lighting and enhanced passenger cabin ventilation and air conditioning systems.
	Dash 8-400	Stretched version (70 pass) of the Dash 8-300. Faster cruise speed Will incorporate redesigned inboard leading edge, new nacels, stronger landing gear and 6 blade propellers. Under consideration.
Manufacturer: Deutsche Aerospace (Germany)		
Dornier 228: 1982	Dornier 228?	A technologically advanced successor (pressurized follow on) of the Dornier 228 (19 seat). Under consideration; launch decision to be made in 1992.
Dornier 328: 1993		The Dornier 328 is not a stretched version of the 228. It has a new fuselage and wing shape, but incorporates the high wing concept of the Dornier 228. It is a faster turboprop, making extensive use of composites in the construction of the wing and fuselage.
	Dornier 328 S	A 48 passenger stretch of the 328 to be delivered in 1996. A stretch of 6.8 m by installing plugs fore and aft wing. The center fuselage will be strengthened and wing extended and beefed up for higher take off weight. There will be a high degree of commonality between the two aircraft.
Manufacturer: Fairchild (USA)		
Metro 1970	Metro III 1981	Current version of the Metro introduced in 1970,derived from corporate aircraft modified for commercial use.

Annex Table 2: REGIONAL AIRCRAFT FAMILIES

Basic model/service date	Family members/service date	Description
	Metro 23C May 1992	A 19 seat more powerful variant of the Metro III with few improvements. Increase in gross weight to 16,500 lb. Aircraft will be quieter but will not have a stand up cabin.
	Metro 23 EP	A new expanded fuselage (EP) option of the Metro 23 aircraft. Offering 130 cu ft additional and 875 lb of payload capacity. Announced in 1991.
	Metro 25	Stretched (25 seat) version of the Metro with an underbelly cargo pod. Project introduced in 1989. Under consideration in 1990.
	Metro V	Stand up cabin variant of the Metro series which development started in 88.Program was tabled when Fairchild found itself in financial trouble and has been delayed since. It is not sure it will ever be launched.
Manufacturer: Fokker (Netherlands)		
Fokker F27: 86	Fokker F28: ?-87	Stretched version of the 50 passenger Fokker 27 fanjet.?
	Fokker 50-100 Aug. 87	The Fokker 50 structure is based on that of the F27 and makes extensive use of adhesive bonded assemblies to form the primary structure.
	Fokker 50-300 Aug. 87	"High & hot" version of the Fokker 50-100, same seat arrangement.
	Fokker 100 April 88	A 91-120 stretched version of the Fokker 28.?
	Fokker 54	Unveiled in 1990. A variant of the Fokker 50. Not a stretch. Increase in passenger capacity is a rearrangement of the interior eliminating the forward cargo hold and door.
	Fokker 130	A standard 137 seat derivative of the Fokker 100 with a stretched fuselage and wing root plugs. Increased wingspan and higher thrust engines. New landing gear. Feasibility study to be completed in 1991.
	Fokker 80	Slightly stretched fuselage of the F28 with standard capacity for 77 passenger to avoid penalties of shrinking an aircraft. Incorporates advanced technology of the Fokker 100 where feasible in the engines, wing and aerodynamic systems. Feasibility study to be completed in 91.
	Fokker 50-400	Stretched version of the Fokker 50 with capacity of up to 68 passengers.

Annex Table 2: REGIONAL AIRCRAFT FAMILIES

Basic model/service date	Family members/service date	Description
	Fokker QC	A "quick change" version of the Fokker 100 jetliner to be available in 1994. Installation of a cargo door in the left forward section of the fuselage and specially designed cabin interior.
Manufacturer: Saab (Sweden)		
Saab 340: Jun. 84	Saab 2000 Sep. 93	The aircraft - a 50 seat high speed turboprop with jetlike comfort-drives many of its features from the Saab 340. Few major components of the two aircraft are interchangeable.The 2000 was designed to fit into jigs designed for the 340 for steps such as the robotic riveting and assembly. The 2000 cockpit has roughly 1200 parts of which 800 have same part number as the 340. Integration of the 340/2000 production continues virtually through final assembly. The 2000 has a completely new wing and is substantially longer than its predecessor at 88.69ft. According to manufacturer, the next generation of the Saab family will incorporate the technical improvements of the Saab 2000 on an aircraft the size of the 340.
Manufacturer: Short Brothers (Northern Ireland)		
Shorts 330: 70s.	Shorts 360 1982	A 36 seat stretched and more powerful version of the 30 seat 330. Engines twice increased.Unpressurized. New lightweight reclining seats. Airconditioning introduced. Six blade propeller for lower internal and external noise.
FJX		The 44-48 seater jetliner, if launched is expected by Short to succeed the unpressurized 330/360 programs. Short was looking for partners to build the aircraft before it was sold to Bombardier.
Manufacturer: Czechoslovakia Aerospace Industry		
LET 410: 1969	LET 610	Stretched version (?) of the 19 seat LET 410 with capacity for 40 passengers. Maiden flight in 1988.
	LET?	Company has plans to build a stretched version of the LET610,possibly with 50 seats, but will start moving on project only after the 42 seat has been certified.

INDUSTRY SERIES PAPERS

No. 1 Japanese Direct Foreign Investment: Patterns and Implications for Developing Countries, February 1989.

No. 2 Emerging Patterns of International Competition in Selected Industrial Product Groups, February 1989.

No. 3 Changing Firm Boundaries: Analysis of Technology-Sharing Alliances, February 1989.

No. 4 Technological Advance and Organizational Innovation in the Engineering Industry, March 1989.

No. 5 Export Catalyst in Low-Income Countries, November 1989.

No. 6 Overview of Japanese Industrial Technology Development, March 1989.

No. 7 Reform of Ownership and Control Mechanisms in Hungary and China, April 1989.

No. 8 The Computer Industry in Industrialized Economies: Lessons for the Newly Industrializing, February 1989.

No. 9 Institutions and Dynamic Comparative Advantage Electronics Industry in South Korea and Taiwan, June 1989.

No. 10 New Environments for Intellectual Property, June 1989.

No. 11 Managing Entry Into International Markets: Lessons From the East Asian Experience, June 1989.

No. 12 Impact of Technological Change on Industrial Prospects for the LDCs, June 1989.

No. 13 The Protection of Intellectual Property Rights and Industrial Technology Development in Brazil, September 1989.

No. 14 Regional Integration and Economic Development, November 1989.

No. 15 Specialization, Technical Change and Competitiveness in the Brazilian Electronics Industry, November 1989.

No. 16 Small Trading Companies and a Successful Export Response: Lessons From Hong Kong, December 1989.

No. 17 Flowers: Global Subsector Study, December 1989.

No. 18 The Shrimp Industry: Global Subsector Study, December 1989.

No. 19 Garments: Global Subsector Study, December 1989.

INDUSTRY SERIES PAPERS *cont'd*

No. 20 World Bank Lending for Small and Medium Enterprises: Fifteen Years of Experience, December 1989.

No. 21 Reputation in Manufactured Goods Trade, December 1989.

No. 22 Foreign Direct Investment From the Newly Industrialized Economies, December 1989.

No. 23 Buyer-Seller Links for Export Development, March 1990.

No. 24 Technology Strategy & Policy for Industrial Competitiveness: A Case Study of Thailand, February 1990.

No. 25 Investment, Productivity and Comparative Advantage, April 1990.

No. 26 Cost Reduction, Product Development and the Real Exchange Rate, April 1990.

No. 27 Overcoming Policy Endogeneity: Strategic Role for Domestic Competition in Industrial Policy Reform, April 1990.

No. 28 Conditionality in Adjustment Lending FY80-89: The ALCID Database, May 1990.

No. 29 International Competitiveness: Determinants and Indicators, March 1990.

No. 30 FY89 Sector Review Industry, Trade and Finance, November 1989.

No. 31 The Design of Adjustment Lending for Industry: Review of Current Practice, June 1990.

No. 32 National Systems Supporting Technical Advance in Industry: The Brazilian Experience, June 26, 1990.

No. 33 Ghana's Small Enterprise Sector: Survey of Adjustment Response and Constraints, June 1990.

No. 34 Footwear: Global Subsector Study, June 1990.

No. 35 Tightening the Soft Budget Constraint in Reforming Socialist Economies, May 1990.

No. 36 Free Trade Zones in Export Strategies, December 1990.

No. 37 Electronics Development Strategy: The Role of Government, June 1990

No. 38 Export Finance in the Philippines: Opportunities and Constraints for Developing Country Suppliers, June 1990.

<u>INDUSTRY SERIES PAPERS</u> *cont'd*

No. 39 The U.S. Automotive Aftermarket: Opportunities and Constraints for Developing Country Suppliers, June 1990

No. 40 Investment As A Determinant of Industrial Competitiveness and Comparative Advantage: Evidence from Six Countries, August 1990 *(not yet published)*

No. 41 Adjustment and Constrained Response: Malawi at the Threshold of Sustained Growth, October 1990.

No. 42 Export Finance - Issues and Directions Case Study of the Philippines, December 1990

No. 43 The Basics of Antitrust Policy: A Review of Ten Nations and the EEC, February 1991.

No. 44 Technology Strategy in the Economy of Taiwan: Exploiting Foregin Linkages and Investing in Local Capability, January 1991

No. 45 The Impact of Adjustment Lending on Industry in African Countries, June 1991.

No. 46 Banking Automation and Productivity Change: The Brazilian Experience, July 1991.

No. 47 Global Trends in Textile Technology and Trade, December 1991.

No. 48 Are There Dynamic Externalities from Direct Foreign Investment? Evidence for Morocco, December 1991.

No. 49 Do Firms with Foreign Equity Recover Faster From Financial Distress? The Case of Colombia, December 1991

No. 50 International Competition in the Bicycle Industry: Keeping Pace with Technological Change, December 1991.

No. 51 International Competition in the Footwear Industry: Keeping Pace with Technological Change, December 1991.

No. 52 International Trends in Steel Mini-Mills: Keeping Pace with Technological Change, December 1991.

No. 53 International Competition in Printed Circuit Board Assembly: Keeping Pace with Technological Change, December 1991.

No. 54 Efficiency, Corporate Indebtedness and Directed Credit in Colombia, December 1991.

No. 55 Small Enterprises Under Adjustment in Senegal, Maarch 1992.

No. 56 Fundamental Issues and Policy Approaches in Industrial Restructuring, April 1992

No. 57 Building a Competitive Edge in Sub-Saharan African Countries: The Catalytic Role of Foreign and Domestic Enterprise Collaboration in Export Activities, April 1992.

No. 58 Learning, Technical Progress and Competitiveness in the Commuter Aircraft Industry: An Analysis of Embraer, June 1992.

No. 59 Productivity and Industrial Development in Sub-Saharan Africa, June 1992.

Note: For extra copies of these papers please contact Miss Wendy Young on extension 33618, Room S-4101, fax (202) 477-0561.

World Bank Industry and Energy Dept.

ENERGY SERIES PAPERS

No. 1 Energy Issues in the Developing World, February 1988.

No. 2 Review of World Bank Lending for Electric Power, March 1988.

No. 3 Some Considerations in Collecting Data on Household Energy Consumption, March 1988.

No. 4 Improving Power System Efficiency in the Developing Countries through Performance Contracting, May 1988.

No. 5 Impact of Lower Oil Prices on Renewable Energy Technologies, May 1988.

No. 6 A Comparison of Lamps for Domestic Lighting in Developing Countries, June 1988.

No. 7 Recent World Bank Activities in Energy (revised October 1989).

No. 8 A Visual Overview of the World Oil Markets, July 1988.

No. 9 Current International Gas Trades and Prices, November 1988.

No. 10 Promoting Investment for Natural Gas Exploration and Production in Developing Countries, January 1989.

No. 11 Technology Survey Report on Electric Power Systems, February 1989.

No. 12 Recent Developments in the U.S. Power Sector and Their Relevance for the Developing Countries, February 1989.

No. 13 Domestic Energy Pricing Policies, April 1989.

No. 14 Financing of the Energy Sector in Developing Countries, April 1989.

No. 15 The Future Role of Hydropower in Developing Countries, April 1989.

No. 16 Fuelwood Stumpage: Considerations for Developing Country Energy Planning, June 1989.

No. 17 Incorporating Risk and Uncertainty in Power System Planning, June 1989.

No. 18 Review and Evaluation of Historic Electricity Forecasting Experience, (1960-1985), June 1989.

No. 19 Woodfuel Supply and Environmental Management, July 1989.

No. 20 The Malawi Charcoal Project - Experience and Lessons, January 1990.

No. 21 Capital Expenditures for Electric Power in the Developing Countries in the 1990s, February 1990.

No. 22 A Review of Regulation of the Power Sectors in Developing Countries, February 1990.

No. 23 Summary Data Sheets of 1987 Power and Commercial Energy Statistics for 100 Developing Countries, March 1990.

No. 24 A Review of the Treatment of Environmental Aspects of Bank Energy Projects, March 1990.

No. 25 The Status of Liquified Natural Gas Worldwide, March 1990.

No. 26 Population Growth, Wood Fuels, and Resource Problems in Sub-Saharan Africa, March 1990.

No. 27 The Status of Nuclear Power Technology - An Update, April 1990.

No. 28 Decommissioning of Nuclear Power Facilities, April 1990.

No. 29 Interfuel Substitution and Changes in the Way Households Use Energy: The Case of Cooking and Lighting Behavior in Urban Java, October 1990.

No. 30 Regulation, Deregulation, or Reregulation--What is Needed in LDCs Power Sector? July 1990.

No. 31 Understanding the Costs and Schedules of World Bank Supported Hydroelectric Projects, July 1990.

No. 32 Review of Electricity Tariffs in Developing Countries During the 1980s, November 1990.

No. 33 Private Sector Participation in Power through BOOT Schemes, December 1990.

No. 34 Identifying the Basic Conditions for Economic Generation of Public Electricity from Surplus Bagasse in Sugar Mills, April 1991.

No. 35 Prospects for Gas-Fueled Combined-Cycle Power Generation in the Developing Countries, May 1991.

No. 36 Radioactive Waste Management - A Background Study, June 1991.

No. 37 A Study of the Transfer of Petroleum Fuels Pollution, July 1991.

No. 38 Improving Charcoaling Efficiency in the Traditional Rural Sector, July 1991.

No. 39 Decision Making Under Uncertainty - An Option Valuation Approach to Power Planning, August 1991.

No. 40 Summary 1988 Power Data Sheets for 100 Developing Countries, August 1991.

No. 41 Health and Safety Aspects of Nuclear Power Plants, August 1991.

No. 42 A Review of International Power Sales Agreements, August 1991.

No. 43 Guideline for Diesel Generating Plant Specification and Bid Evaluation, September 1991.

No. 44 A Methodology for Regional Assessment of Small Scale Hydro Power, September 1991.

No. 45 Guidelines for Assessing Wind Energy Potential, September 1991.

No. 46 Core Report of the Electric Power Utility Efficiency Improvement Study, September 1991.

No. 47 Kerosene Stoves: Their Performance, Use, and Constraints, October 1991.

No. 48 Assessment of Biomass Energy Resources: A Discussion on its Need and Methodology, December 1991.

No. 49 Accounting for Traditional Fuel Production: the Household-Energy Sector and Its Implications for the Development Process, March 1992.

No. 50 Energy Issues in Central and Eastern Europe: Considerations for the World Bank Group and Other Financial Institutions, March 1992.

For copies, please call (202) 473-3616 or extension 33616.