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Aerospace Clusters: Local or Global Knowledge Spillovers?

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ABSTRACT The literature about regional innovation systems, clusters and industrial districts insists on the importance of local knowledge spillovers. Nevertheless, more recently a few authors have put in question the importance of local knowledge spillovers. This paper provides an analysis of some of the most dynamic aerospace clusters in the world, located in Montreal, Seattle, Toulouse and Toronto. We start by discussing theories of clustering, then provide research questions as well as empirical evidence on the international nature of knowledge spillovers. Local knowledge spillovers are less significant, of a different nature, and they may make a scanty contribution to explain the geographical agglomeration of firms. Conversely, international spillovers help to explain the relative dispersion of industry across nations. Resilient geographical clustering is related to the anchor tenant effects as creators of labour pools and owners of very large manufacturing plants creating regional inertia. We thus reject the local knowledge spillover explanation of aerospace clusters in favour of another one based on anchor firms and their effects on the local labour pool.

The aerospace industry is one of the largest high-technology employers in advanced countries. By 2000, there were 1,220,000 aerospace employees in the world, of whom 49 per cent were in the USA, 35 per cent in the European Union, 7.5 per cent in Canada, 2.7 per cent in Japan and 5.7 per cent in the rest of the world (Table 1). Within this industry, the civil aviation manufacturing sector is the most important: in 2000, 66 per cent of European aviation manufacturing employees were in civil production and 33 per cent in the military sector. The figures in the USA were 59 and 41 per cent, respectively.

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Table 1. Comparative aerospace industry employment, 2000

Country/region	Percentage of employment
USA	49.9
European Union	35.2
Canada	7.5
Japan	2.7
Rest of the world	5.7
Total	100 (1,220,000)

In the last 10 years, civil aircraft original equipment manufacturers (OEMs) have been competing for orders from airline companies, whose revenues have been declining. The four major civil aircraft prime contractors are Airbus and Boeing (for planes over 100 seats) and Bombardier and Embraer for regional jets. To reduce costs, aerospace OEMs have increased their outsourcing to suppliers of subassemblies (such as engines, structures, landing gear and avionics) and concentrating on their core competencies of design, assembling and marketing aircraft. At the same time, they have made efforts to reduce, reorganize and rationalize their supply base. Thus, knowledge management in the supply chain has become critical (Bozdogan *et al.* 1998; Gostic 1998; Allen *et al.* 2002). Also, due to the increasing use of just-in-time and other supply chain methods, production has tended to concentrate in a few cities, our regional aircraft clusters, which include Montreal, Seattle, Toronto and Toulouse. However, international outsourcing has produced international spillovers[1] and created new poles of growth, mainly in South East Asia.

This paper is about the dynamics of the clusters and the nature of knowledge spillovers that occur within and among aerospace clusters. Section 1 recalls theories and presents the research questions. Section 2 recalls the characteristics of the aerospace industry and Section 3 presents data on clusters. Section 4 goes back to the theoretical discussion about regional and international knowledge spillovers. A conclusion puts the new data in a more general perspective.

1. Theory

Clustering and dispersion of industry are submitted to opposing forces. Centripetal forces tend to concentrate industry in a few geographical regions. Centrifugal forces push in the opposite direction and tend to

[1] In this paper we use the concept of spillover and externalities as synonymous. Both refer to unintended benefits or losses that some economic agents impose on others. “Flows” refer to both spillovers and also contractual, conscious exchange.

disperse industry across regions and nations. This section will review some of these forces, with an emphasis on the role of local versus international knowledge spillovers. We oppose the tenants of the dominance of centripetal forces, most prominent among them being local knowledge spillovers, and the followers of a more recent tradition suggesting that international externalities have become more conspicuous. This paper intends to examine how well these opposing theories explain geographical clustering in aerospace.

1.1. Centripetal Factors

Regional agglomerations of high-technology firms were analysed using different frameworks and different concepts. These concepts include industrial districts (the Marshall tradition), regional poles (the Perroux model), clusters and regional systems of innovation, to name just a few.

The industrial district tradition, based on Alfred Marshall's seminal studies in the late 1800s and early 1900s, is about agglomeration of small and medium-sized companies in the same or related industries (Meardon 2001). Universities, government policies and public laboratories play a very small role in these districts. These are self-organized agglomerations of private firms competing in similar markets, together with specialized suppliers of equipment and services. This tradition has captured the imagination of Italian social scientists, who have produced a very rich set of studies using this framework. Marshallian externalities have been summarized as either economies of specialization, labour market economies (based on the local human capital pool) and/or knowledge spillovers.

Another tradition, based on François Perroux' work, is more about regional poles built around "industrializing industries", that is, sectors such as transportation equipment, that attract upstream manufacturers of parts and components, as well as metal, primary metals, rubber, plastic products and glass manufacturing attracting downstream producers using these materials. Such regional agglomerations do not require supporting institutions like universities or government laboratories. In the postwar period, European governments (particularly in France and Italy) applied this concept of Perroux poles in an effort to develop backward areas. Knowledge externalities, in this tradition, do not play a major role; agglomeration is more an input–output fact, based on demand created by prime contractors.

In the late 1980s and 1990s, two different major currents have developed in the USA and Western Europe. One, mostly based in the USA, emphasizes local knowledge spillovers, non-market scientific and technological leakages from research universities and public laboratories as major explanations for the clustering of high-technology firms. Authors like David Audretsch, Maryann Feldman, Rebecca Henderson, Adam Jaffe and Manuel Trajtenberg (see the chapter by Feldman 2000 for an overview of the literature) tried to measure these spillovers with different levels of accuracy, but mostly through citations of patents and scientific literature.

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Against this current, Krugman (1991) suggested that these spillovers, if they exist, do not leave any track, and thus, scientific attention should be devoted to other, more relevant issues.

The other current is about local and regional systems of innovation. Philip Cooke and Kevin Morgan (1998), based on the work of Bengt-Åke Lundvall, Chris Freeman and Richard Nelson, and later Charles Edquist and Jeremy Howells, emphasized the dynamics between several organizations and institutions such as innovative firms, research universities, public research institutions and government incentives. Regions which possess the full panoply of innovation organizations set in an institutional milieu, where systemic linkage and interactive communication among the innovation actors is normal, approach the designation of regional innovation systems (Cooke and Morgan 1998).

Finally, Michael Porter has suggested that his famous diamond can be applied to innovative clusters as well. He defines clusters as geographical concentrations of interconnected companies and institutions in a particular field. The dynamic nature of clusters, he suggests, is based upon inter-firm local competition, the supply of equipment and services, input factor (human capital, research infrastructure, venture capital) and demand factor (sophisticated local users) (Porter 1998, 2001). In Porter's view, like in Perroux, clusters are tightly linked input–output systems. Externalities do not play a role in his theory.

More recently, the concept of anchor firms, attracting human capital and specialized suppliers and providing knowledge spillovers has come to the forefront (Feldman 2003). The anchor hypothesis has never been applied to aerospace, but it may provide some elements of explanation about geographical clustering in this industry.

1.2. Centrifugal Factors

Even if a growing literature relates local knowledge spillovers and regional agglomeration of industry, another current tends to emphasize the international dispersion of industrial activity. The latter current links cross-border externalities with the increasing internationalization of economic activity. Through foreign direct investment (FDI), foreign patenting, international R&D collaboration and international trade, knowledge flows across borders have increased exponentially in the postwar period (Coe and Helpman 1995; Baldwin *et al.* 1999; Xu 2000). The theory and measurement of these international externalities is as recent and unstable as the concepts and dimensions of regional spillovers (Branstetter 2000). However, some of the mechanisms of these spillovers are already known, such as face-to-face meetings involved in both FDI and international alliances as well as the international transfer of blueprints, manuals and personnel.

International spillovers are not the only factors that disperse industry across nations. The product life cycle theory postulates that, as process

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technology becomes more standardized and non-proprietary, dominant designs appear, and markets become global, companies start competing on the basis of price. Thus they tend to locate in nations where costs are lower and new markets for mature products are still open (Vernon 1966). Thus, new products are normally launched in developed nations, where consumers are more affluent and ready to take risks in the acquisition of novel goods and services. As average costs decline, products are first exported to other affluent nations, and then to the more advanced new industrializing countries. Production follows markets, as the innovators create foreign facilities in order to restrain the entry of competitors from low cost regions. Alternatively, they can outsource parts and components in less developed nations, thus taking advantage of lower costs and being exposed to lower risks than through FDI.

Agglomerations of high-technology firms are not necessarily regional innovation systems. From the abundant theory and studies on multinational corporations, we know that advanced technology products may have been designed and researched in one area (or several geographic areas) and produced in other regions. These include pharmaceutical products that large multinational corporations develop in numerous expatriate laboratories located in different countries (Taggart *et al*. 2001). Also, both aircraft and telecommunication equipment may be developed in one or several locations, offering advantages for R&D, and produced in other locations with comparative advantages for production. Thus, regional agglomerations of aircraft firms may exploit some local advantages (including cheap work-force, tax credits or government subsidies) without major interaction and learning processes going on within the region. Also, clustering may occur because of the existence of a specific advantage in a region, such as a labour pool or government incentives.

1.3. Research Questions

We developed two major research questions to explain aerospace clusters, on the basis of the theoretical literature on clusters and spillovers. The first one concerns knowledge production and associated spillovers.

1. Which activities within the aerospace industry cluster and which do not?
2. What may explain such clustering?

2. Aerospace Industry: Local or Global

2.1. Introduction

Strategically vital for the national economy and security, the aircraft industry has been observed by scholars mostly from a national or regional point of view (Eriksson 1995). Diverse studies demonstrate some positive influence of clustering in the industry performance (Beaudry 2001). But

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others suggest that in the case of aerospace firms agglomerative advantages are operating weakly (Lublinski 2003).

The dominant characteristics of the aircraft industry are helpful in explaining why traditional centralization factors do not apply. Aerospace is a high value-added sector, strongly affected by scale and timing. The industry success depends on rapid technological progress; government support for corporate R&D is essential. Their activity depends on components and parts which can be widely dispersed in terms of both industry and location. Transportation costs of these components are not relevant in overall aircraft costs. Also, demand (market) is not geographically bounded.

The analysis of recent developments in the aerospace sector reveals that the primary centripetal force has been the regional pool of skilled and semi-skilled labour. Less important factors have been the location to the original industries of the cluster (often engineering sectors close to aircraft such as railway manufacturing) and the entrepreneurial talent (Cunningham 1951; Todd and Simpson 1986). History offers numerous cases of government deciding industrial location or relocation. These decisions have combined national strategic interests with regional development policies, as appears in the history of the aircraft industry in Canada, France, Italy and the USA. The persistent increase of R&D costs has been the major centrifugal force for the aircraft global decentralization: in order to reduce R&D costs, the industry has been gradually implementing strategies of international cooperation.

Aerospace production is scattered throughout Western Europe and North America, suggesting major international and inter-regional knowledge flows. Table 2 gives an indication of the size of the top 12 aerospace clusters in North America. California dominates with two major clusters

Table 2. Top North American aerospace metropolitan areas, 2000

Rank	Metropolitan area	Number of aerospace jobs
1	Los Angeles, CA	107,500
2	Seattle, WA	95,500
3	Washington, DC	45,000
4	Wichita, KS	40,000
5	New York, NY	33,500
6	**Montreal, Que.**	26,000
7	Dallas, TX	24,500
8	Boston, MA	20,500
9	Philadelphia, PA	19,500
10	San Francisco, CA	19,500
11	Atlanta, GA	11,500
12	**Toronto, ON**	8,000

Note: Business establishments with 100 employees or more.
Source: Pricewater Cooper and or estimates.

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which, together with Washington State, represent close to 50 per cent of US aerospace employment. Conversely, there is a much larger dispersion in European industry, where all 15 countries have some aerospace activity, due to historical reasons (Table 3). The UK, France and Germany, however, represent over 50 per cent of the 429,000 European aerospace employees. Toulouse is by far the most important cluster in Europe, with 25,000 aerospace employees. No study has compared the efficiency and effectiveness of such widely divergent arrangements. Krugman (1991) has suggested that the similar geographical dispersion of the European auto industry is inefficient and may be explained by political rather than economic reasons. However, aircraft are produced in short runs, and increased transportation costs due to geographic dispersion may not be as important in aerospace as they are in the auto industry.

Economic concentration in this industry is very high. For each sector (large civilian aircraft, regional aircraft, business jets, helicopters, etc.) there are only a few competitors. Barriers to entry are very high due to capital commitments required to design and produce aircraft. Competition among the few is however strong. The industry is hierarchically organized into "tiers". At the top of the pyramid one finds the airframe assemblers (prime contractors or OEMs) such as Airbus, Bell Helicopter Textron, Boeing, Bombardier, Embraer and Eurocopter. These companies design planes and helicopters, prospect markets and order subassemblies from the second tier. At this second level, we find manufacturers of propulsion systems such as General Electric, Pratt & Whitney or Rolls-Royce. Producers of on-board avionics, such as Honeywell in the USA and Sextant Avionique in France, also belong to this category. Tier 2 also includes manufacturers of airframe structures and subassemblies such as landing gear, nacelles and hydraulic systems. Messier-Dowty (France) and Héroux-Devtek (Canada), both producers of landing gear, belong to this category. Tier 3, producers of

Table 3. European aerospace clusters, 2000

Country	Number of aerospace jobs	Main clusters
UK	150,000	Bristol, Lancashire, Farnborough
France	101,000	Toulouse, Bordeaux, Ile-de-France
Germany	70,000	Bavaria, Hamburg/Bremen
Italy	39,000	Turin, Milan, Naples
Spain	18,000	Madrid, Bilbao
Sweden	13,000	Linkoping, Göteborg
Netherlands	11,000	Amsterdam
Belgium	7,000	Sonaca
Ireland	4,000	Dublin
Portugal	4,000	Lisbon
Austria	4,000	Vienna
Greece	4,000	Athens

electronic subassemblies, hydraulic systems and fuselage parts, is also a very concentrated group of producers at the global level with a handful of firms dominating each segment. Figure 1 summarizes the relationship between the three tiers. Knowledge usually flows from the top down, but some information moves up, mostly from tier 2 firms to tier 1 firms.

One other group of firms is usually added to the pyramid. Aerospace clusters always include hundreds of small and medium manufacturers offering parts and components assembled by tier 2, 3 and sometimes by tier 1 firms. Even if these firms often get most of their revenues from the aerospace industry, they are also offering their products and services to a large range of other industries.

Most large aerospace clusters thus consist of one or several OEMs surrounded by hundreds of small and medium-sized tier 4 suppliers of components and parts. In aerospace clusters, knowledge spillovers are technology based and centred on supply chain management linking the OEMs and their suppliers. Unlike biotechnology, in the study of aerospace spillovers, citations to patents and licensing are useless as measurement methods: these companies do not usually publish scientific papers, or license technology, and their processes are most often protected through secrecy rather than patents. *Supply chain management is the vehicle of knowledge spillovers in this industry. This chain is basically international.* Supply chain management includes such dimensions as technical specifications, concurrent engineering, strategic engineering alliances, quality control, product

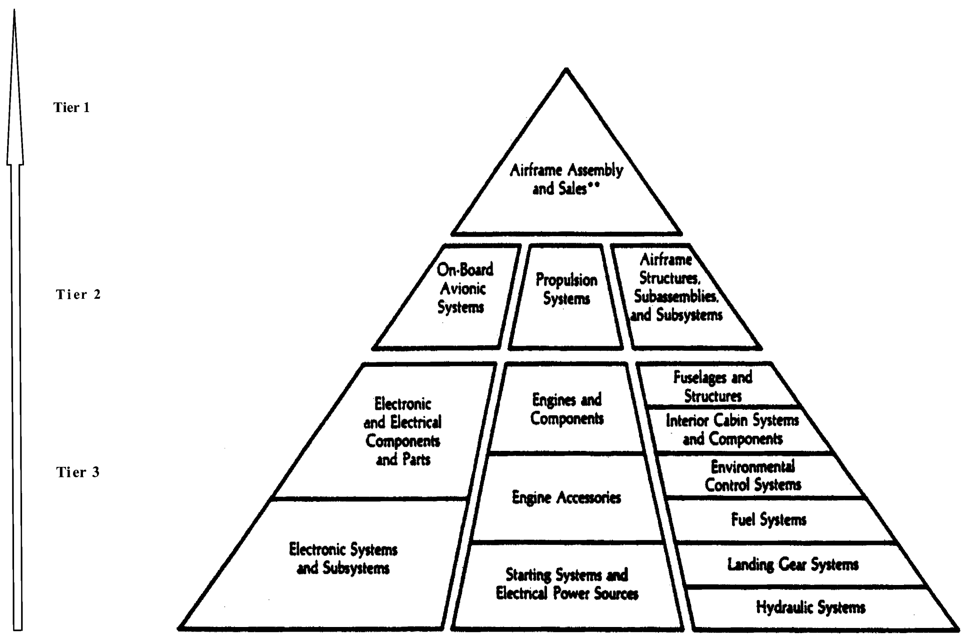

Figure 1. The producers' pyramid

co-development, certification of suppliers, delivery time, risk-sharing, cost-sharing, production volumes and prices (Bozdogan *et al.* 1998; Gostic 1998). Aerospace prime contractors have moved from arm's length American-style procurement practices to more "Japanese" inspired supply chain collaboration with both OEMs of subassemblies and suppliers exchanging knowledge on products, processes and costs. Inter-firm teams and OEM training schemes aimed at the suppliers are major mechanisms to transfer knowledge from one organization to another, across borders and regions.

Aerospace regions are specialized. They manufacture high-value products, in batches from a few hundred to several thousand. Their major components (aircraft, fuselages, wings, engines, avionics, landing gear) can be shipped from one place to another, transportation costs being a small fraction of total costs. Thus, there are civil aircraft assembly clusters (such as Montreal, Seattle or Toulouse), engines clusters (around GE's engine plants in Cincinnati, Ohio and Lynn, Massachusetts). With Boeing as a major assembler, Seattle is specialized in engineering and production of large commercial aircraft. Toulouse (France) is the major production site of Airbus and ATR. All these aircraft regions have been active in the aerospace industry for as long as one century (Toulouse) or at least 50 years (Fort Worth). The specialization of regions in different nations reinforces the international spillovers in this industry, as the regions where systems integrators are based "import" engines or fuselages from regions of other nations where these are produced.

Aerospace clusters are characterized by major geographical inertia due to heavy sunk costs in large plants with costly and complex sophisticated equipment that cannot be easily moved from one location to another. Contrary to biotechnology and software, where human capital is dominant, large aerospace plants are used for decades. Also, the industry is characterized by increasing returns: successful companies tend to gain market share and thus increase the size of the existing plants, build new plants in the same region or absorb other companies' plants in the same region or in other ones. For these reasons, aerospace clusters are long-term phenomena. As regional agglomerations do not disappear but get more specialized, thus international flows are reinforced by the long-term trend.

2.2. Internationalization of the Aircraft Industry

Four periods of internationalization may be distinguished in the evolution of the aircraft industry: (1) the period of the USA's industrial supremacy; (2) the European catching up; (3) the duopolistic war between Airbus and Boeing; and (4) the worldwide diffusion of the industry.

From the end of World War II until the beginning of the 1960s, the USA's predominance was absolute, in terms both of production and market. During this period, the American aircraft supply chain remained dispersed but only in a national base. In the meantime, the USA protected its domestic aircraft market. The "Buy American Act" was the strong protection mechanism, imposing penalties on US government agencies who preferred importing foreign over domestic equipment (Todd and Simpson 1986). None of the European countries had by itself the technological and financial capabilities of the American aircraft industry. Thus, they had no other choice but to purposely initiate and develop international relationships, mostly through intra-European cooperation.

During the 1970s, the European countries reinforced this strategic industry and accelerated the creation of the Airbus consortium. The American aerospace sector was quickly involved in the new oligopolistic war. There were clear signals from the other side of Atlantic, announcing the end of American leadership.

By the end of the 1980s and during the 1990s, international cooperation between different members of the aircraft value chain became commonplace for both American and European firms. With the "better, faster, cheaper" era of aircraft, time came when even the American giant industry could not afford either high technological and financial efforts, or market risks related to the new development programs. As Esposito (2004) demonstrates, the success of aircraft firms is based on the existence of a complex network of long-term relationships having an "evolutionary" nature where collaboration and competition exist hand in hand. Hagedoorn (2002) points out that international R&D partnering in aerospace and defence is well above the average compared to other high-tech industries. During the 1990–98 period this industry had the highest international partnering index of all sectors.

Nowadays, it is not anymore possible to overlook the global integration of the aircraft industry. The six big European and American groups emerging from an intensive industrial concentration process are pushing for more and stronger technological competition in their market segments, and at the same time are reinforcing their international R&D collaboration.

The emergence of the aerospace industry in other counties is evident. The geopolitical ambitions have strongly motivated governmental actions for the development of the aircraft industry. This will has nurtured a form of cooperation with advanced countries that have helped a few of them (Brazil, China, India, Korea) to accumulate the necessary capabilities for being successful in this sector. One of the most prominent mechanisms for technology transfers in aerospace has been the frequent use of offset agreements. Governments are usually owners of national airlines, thus they have been in a convenient position to impose their conditions on aircraft producers (Mowery 1987; Pan 1996; McGuire 1997). In a first step, these countries have become part of the international aircraft supply chain. In a few years, they will acquire enough specialized technology, know-how and experience allowing them to be active players on a global scale. Few studies are concentrating on this potential competition from the outside of the three decades old USA–EU duopoly (Ericsson 1995; Pritchard 2002). 1

3. The Research

The study consists of a detailed examination of two aerospace clusters (Montreal and Toronto) and a summary comparison to two of the largest aircraft clusters during their growth and decline. The research was conducted through personal interviews with company officials and used secondary data from many different sources.

3.1. A Diversified Montreal Cluster

Montreal represents over 50 per cent of Canada's employment in the aerospace industry. It is the only city in Canada and one of the few in the world where an entire aircraft can be designed. The production of aircraft started in Montreal in the 1920s with several American, British and Canadian producers competing to produce small, regionally flown propeller aircraft. In 1944, a group of Canadian Vickers employees (the Canadian subsidiary of British Vickers, producing aircraft in Montreal) founded Canadair in Ville St-Laurent, in Montreal's north end. After World War II and the cold war, Canadair produced mostly military aircraft. Dozens of companies spun off from Canadair or were attracted to Montreal to supply parts and components for it (Pickler and Milberry 1995). In 1976, the company acquired the exclusive rights to the blueprint of the Learjet 600, a business jet designed by William Lear, of Learjet Corporation, in Wichita, Kansas (Phillips *et al.* 1994). With some local adjustments, the aircraft became the Challenger 600, whose first prototype flew in 1978. In 1986, Bombardier Corporation of Montreal bought Canadair and decided to enter the regional aircraft market with a modified version of the CL600. The development of the regional jet was decided in 1987 and the first prototype flew in 1991; it was the RJ100, accommodating 50 passengers; production was launched in 1993. Several subsequent versions enlarged the regional jet up to 90 seats. In the meantime, in 1992, Bombardier had bought de Havilland in Toronto. In 1989, with the acquisition of Short Brothers by Bombardier in the UK, and that of Learjet in Wichita, Kansas, Bombardier completed a range of aircraft with between 5 and 100 seats. The regional aircraft market is now dominated by turbofan technology; Bombardier was one of the few companies to introduce it. The world market for aircraft had changed radically when, in the late 1980s, the large airlines moved from point-to-point to hub-and-spoke networks requiring large aircraft only for the service of major airports, and regional aircraft for the feeding lines around the hub. The era of regional jets had arrived. In a decade, Bombardier Aerospace, with 15,000 employees in Montreal alone and 28,000 around the globe, became the world's third largest producer of aircraft, and Montreal became a thriving aerospace RSI. In the meantime, 2
Bombardier transferred its aircraft design capabilities for new planes to Montreal. Since these capabilities originated from scattered sites, Bombardier benefited from a new wave of major international knowledge

spillovers. *Canadair, and now Bombardier have become the anchor firms that created the labour pool upon which most other companies have located in the metropolitan area*. Today all its families of business and regional jets are developed in Montreal. General Electric engines manufactured in the USA power most Canadian regional jets (CRJs), which use imported avionics and other major components.

In the 1920s, attracted by the first aircraft producers, Pratt & Whitney Canada (P&WC), a subsidiary of US-based United Technologies, started overhauling and repairing American designed and built aircraft engines. After World War II, P&WC started producing small turbines in Montreal, and incorporated local design capabilities for them (De Bresson *et al*. 1991). Today, the family of P&WC products has expanded. Its engines are entirely designed and manufactured in Montreal, and protected through dozens of US patents (Table 4). These engines are found in some Bell Helicopter Canada (BHC) models manufactured in Montreal. P&WC engines are also powering some of Bombardier's models produced in several plants, including those made in Toronto (DHC-8) and Montreal (water bombers CL-215 and CL-415). P&WC has a total of 6,700 employees in its engineering and production facilities in Montreal's southern end. Over 90 per cent of their products are exported.

In 1984–85, with financial support from the Canadian government, BHC, the main American producer of helicopters, transferred its production capabilities for the manufacturing (but not the design) of its civilian helicopters to Montreal. Like Bombardier, BHC also produced incoming international knowledge spillovers. During the next 17 years, the new Mirabel facility of BHC produced over 2,500 copies of seven successful models that were exported throughout the world. Two of these models use

Table 4. Patents in Canadian aircraft (1976–2002)

Company	Montreal	Toronto	Winnipeg	Vancouver	Halifax	Ottawa	Calgary
Company 1	73	23	7	3	0	0	0
Company 2	12	10	0	0	0	0	0
Company 3	8	4	0	NA	NA	NA	0
Company 4	8	3	NA	NA	NA	NA	NA
Company 5	7	2					
Company 6	3	2					
Company 7	2	2					
Company 8	2	1					
Company 9	2	1					
All other	10	1					
NRC labs	NA	NA	NA	NA	NA	5	NA
Total patents	127	49	7	3	0	5	0

NA=not applicable.
Source: USPTO.

P&WC turbines designed and manufactured in Montreal. All others use US-made Allison engines. All models make use of US-designed and -manufactured shafts and other major parts. BHC employs 1,200 personnel in its plant in Montreal's north end. BHC was also attracted by Montreal's labour pool.

Bombardier Aerospace and P&WC represent over 40 per cent of Montreal aerospace employment. When BHC is added, these three companies employ well over 50 per cent of the total aerospace personnel of Montreal.

Other important companies are also prominent in the regional aerospace cluster. Honeywell Canada (a US subsidiary) is another major avionics manufacturer, with global mandates for several products, bringing highly valuable technological knowledge to Montreal. CMC Electronics (975 employees in Montreal), the former Canadian Marconi Corporation, since the late 1990s under Canadian ownership and control, is Canada's main avionics producer. Its products are not incorporated in Bombardier's planes, but exported to other major aircraft producers. Héroux-Devtek, with 650 employees in Montreal, is a producer of landing gear, used in Bombardier jets, among other (mostly foreign) aircraft. French companies Messier-Dowty (landing gear produced entirely for European customers) and Thales (avionics and a supplier of Bombardier) also deserve to be mentioned. Another major company in Montreal is CAE, the world's largest producer of flight simulators (4,000 employees in Montreal). In all, over 250 manufacturing small and medium-sized companies at different levels constitute the Montreal aerospace cluster (Figure 2). These small and medium-sized enterprises (SMEs), tier 4 firms, represent not more than 20 per cent of the regional cluster employment and produce parts and components for tier 1, 2 and 3 OEMs. A local network of knowledge flows of lesser proportions thus links the four tiers of the regional pyramid. Figure 2 summarizes the composition and dynamics of the Montreal aerospace cluster.

International knowledge spillovers are thus the norm for all the large manufacturers operating in the region. Montreal generates and receives from abroad major knowledge externalities through its tier 1 and 2 producers.

University research and training within the cluster. Some local spillovers are university–industry ones. In 1986, Bombardier funded the first Chair on aeronautical engineering at the École polytechnique, University of Montreal. In 2001, Concordia University hosted the newly created Concordia Institute for Aerospace Design and Innovation (CIADI). CIADI was an initiative of seven major aerospace firms of Montreal (BHC, Bombardier, CAE, CMC, EMS Technologies, PW&C and Héroux-Devtek). These companies wished to increase the inflow of graduates from local universities and increase academic research. Contrary to biotechnology, in which university incubated industry, in aerospace, industry stimulated university to supply ideas and graduates for their existing demand. Consequently, the local

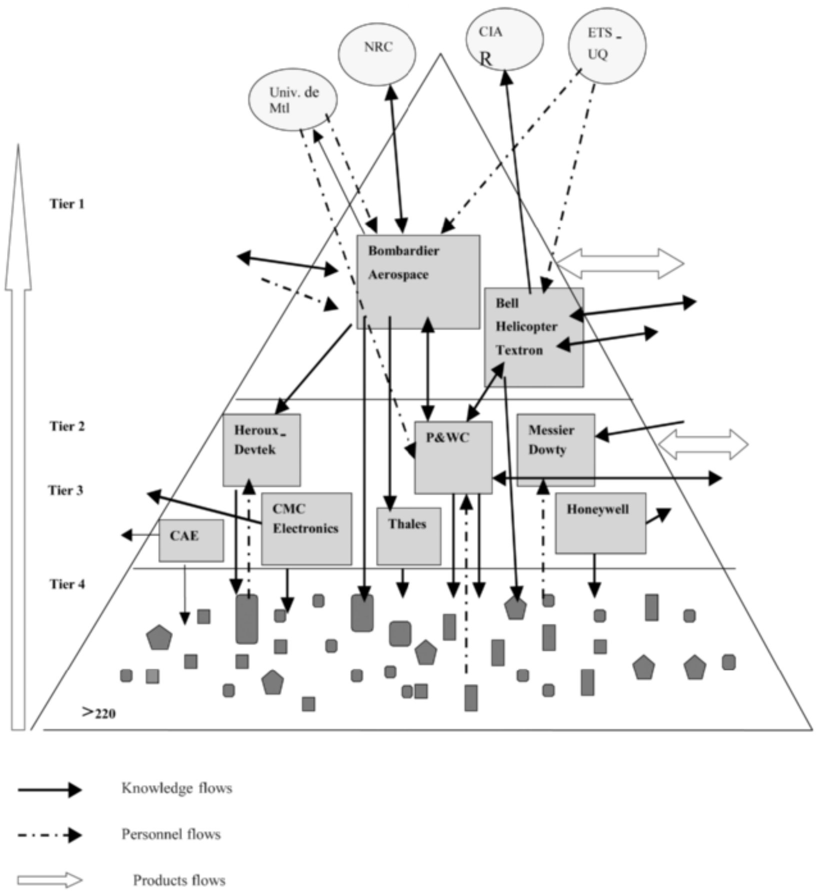

Figure 2. Montreal aerospace cluster

network of knowledge increased, with technology moving from companies to universities.

Government laboratories. Public research institutes contributed, but not significantly, to cluster dynamics or its local spillovers. National Research Council of Canada (NRC) Institutes for Aerospace Research are located in Ottawa. In October 2000, the Canadian government announced the creation of a new NRC facility on aerospace research, this time to be located on the campus of the University of Montreal. The Aerospace Manufacturing Technology Center is now being built.

3.2. *Toronto: An Old and Specialized Cluster*

Toronto represents one quarter of Canada's aerospace employment. One company, De Havilland Canada (DHC), now part of the Bombardier aerospace group, dominates Toronto's regional innovation system in aerospace. DHC was originally founded in 1928 as a subsidiary of the British de Havilland, and started assembling British-made aircraft in the late 1920s. These were small planes used for aerial surveillance and fire identification. Production increased continuously until World War II, when DHC manufactured military aircraft for the Allies' war effort. Over 200 companies clustered around DHC at that time. In 1946, the sudden interruption of government orders reduced employment from 7,000 in 1944 to 200 in 1946 and new companies spun off in the Toronto area. Later on, DHC started designing new aircraft including the very successful DHC-2 Beaver and DHC-3 Otter. New models kept the company afloat until the success of the DHC-6 Twin Otter raised the employment to 7,900 in 1965. However, the company lost ground to competitors and new models and subcontract orders did not materialize. In 1971, DHC employment had dropped below 2,000. In 1974, the Canadian government acquired DHC from its British parent, Hawker Siddeley (the 1966 merger of two British companies Avro and de Havilland). The following year, DHC launched its DHC-7 Dash airliner, and in 1983 it added the Dash-8, a turboprop regional airliner. In 1986, Boeing bought DHC and in 1992 sold it to the Montreal-based Bombardier group. In 1992, DHC had some 3,150 employees in Toronto. By 2002, it employed 5,420 people, and it was one of the largest employers in that metropolitan area. In Toronto, DHC has kept its ability to design entire regional aircraft. Its present models are powered by P&WC engines manufactured in Montreal. By the late 1990s, DHC started producing parts and final assembly of the Global Express, a large business jet designed by Bombardier. In the DHC-8 only the electrical system (Allied Signal) and the landing gear (Menasco Aerospace) were produced in the Toronto region. All the other major elements including avionics (from Sextant Avionique, France), the nacelles (Short Bombardier, Northern Ireland), flap system (Microtecnica, Italy), propellers (Messier-Dowty, France) and hydraulics (Abex, USA) come from abroad. Thus, the DHC supply chain is not particularly linked to other Toronto firms, reducing the potential for major regional knowledge spillovers. DHC needed to control costs and obtain high-quality products. Also, their production is confined to a few hundred copies of each model. As such, they adopt suppliers around the world on the basis of cost, quality and timely delivery, regardless of their location. Figure 3 summarizes DHC's major subassemblies and the location of its suppliers. The figure gives a good indication of the major knowledge spillovers involved in its supply chain. *Even if the regional input–output matrix of large subassemblies is almost empty in Toronto, DHC has served as an anchor firm, the presence of which has created a large labour pool in the region and attracted or spun off hundreds of firms thriving on this skilled labour supply.*

The second largest manufacturer in Toronto is Honeywell Canada, with 1,300 employees mostly in avionics and communications equipment. Even if this is mostly a production site, using imported designs from the USA,

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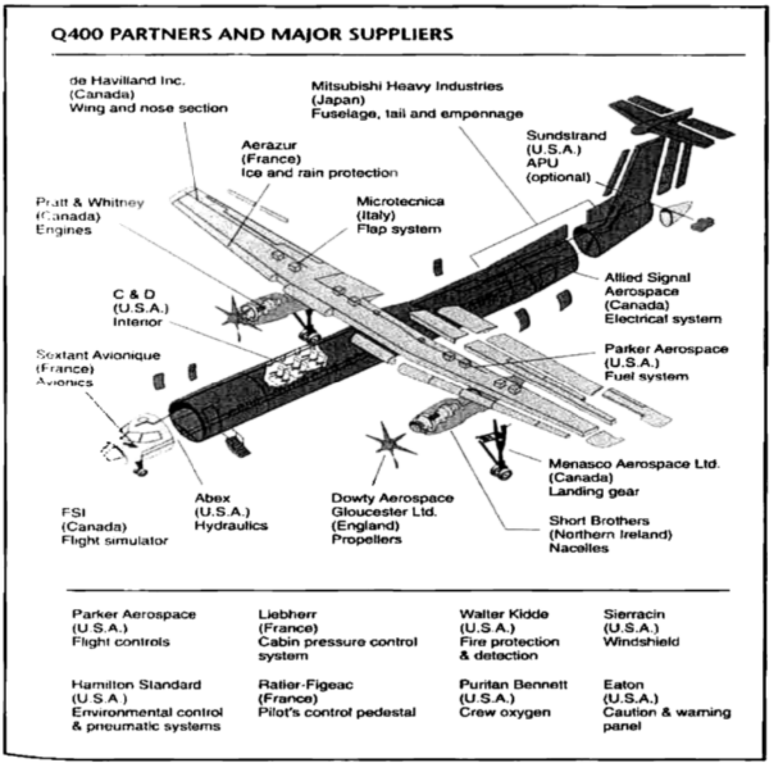

Figure 3. DHC suppliers for the Dash-8

Honeywell has kept some R&D capabilities as witnessed by its patented novelties invented in Toronto. Honeywell's avionics is not intended for local aircraft production. International knowledge spillovers are here overwhelming.

The third major company is Boeing Canada, a tier 2 subsidiary. The original plant belonged to Douglas Corporation that bought it from DHC in 1953. When MacDonnell Douglas became part of Boeing, that plant continued its production of aircraft subassemblies under the control of, and for assembling by, its new parent, which provides US-made designs. In 2002, Boeing had some 800 employees in Toronto.

University research. The University of Toronto provided many of the most skilled engineers working for DHC through the years. The Institute for Aerospace Studies is a 50-year-old institution devoted to research and teaching in areas such as flight simulation and dynamics, materials and structures, propulsion and combustion. It also runs programs and options at both undergraduate and graduate levels. Ryerson University in Toronto also offers an undergraduate program in aerospace engineering. Finally, York University offers an Honours Program in Space and

Communication Sciences in its Faculty of Pure and Applied Science. All these programs have contributed to replenish Toronto's pool of skilled manpower in aerospace. The university–industry link is a channel for some local spillovers.

Government laboratories. Even if federal aerospace labs are located in Ottawa, some collaboration has existed between DHC and NRC laboratories. Reduced versions of the DHC-8 were tested in Ottawa's wind tunnel. Several parts of different aircraft were designed at NRC. The Aerospace Materials Institute has also contributed to different models of the DHC family (Hotson 1998). On the whole, however, DHC was a very independent firm with few inter-regional spillovers from and to NRC government laboratories. There are no local spillovers between public labs and industry in Toronto aerospace.

3.3. Other Major Aircraft Clusters

Toulouse. Based in Toulouse, France, Airbus Industrie is a European consortium, founded in 1969 with a Franco-German lead, and later British and Spanish participation. Its first product, the A300, a 266 seat commercial plane, had British wings, mostly German fuselage, French nose section and lower part of the centre fuselage and Spanish tails. Both GE and P&W in the USA made the engines. Honeywell supplied US-made avionics and Messier-Hispano-Bugatti the landing gear. Toulouse is the main, but not the only, assembly location for Airbus; the second is Hamburg, Germany.

Today, Airbus has become the world's largest producer of commercial aircraft. In 2000, it produced 311 planes in Toulouse. Airbus assembles six different models of aircraft with parts and components coming from 1,500 contractors located in 30 countries. The largest single provider is the USA with over 800 suppliers located in 40 states. In the meantime, Toulouse has become a major aerospace cluster, with hundreds of firms.[2] These include ATR, the Franco-Italian manufacturer of turboprops, which produced 22 turboprops in 2000. Other firms present in the region are Turbomeca (turbines), Messier-Dowty (landing gear for 30 airframers both civil and military, including Airbus) and EADS Socata, the French member of the European consortium. EADS produces small aircraft and structures for Airbus in the region. Toulouse has attracted other aerospace producers not necessarily linked with civil aircraft, such as Matra and Alcatel (satellite telecommunications). In addition to Toulouse, Airbus Industrie has 12 other European production sites, in Breme, Hamburg, Munich and Stade (Germany), Chester (UK), Madrid and Seville (Spain), Amsterdam (Netherlands), Gosselles (Belgium), as well as Meaulte, Nantes and St Nazaire (France).

[2] According to INSEE, in 1997 there were 494 plants in the Toulouse region directly linked to aerospace (INSEE 1997).

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Seattle. In the USA, Boeing started producing aircraft in 1917. Boeing dominated the large commercial aircraft industry for over 50 years, from World War II to the end of the 20th century. It is still the world's largest producer of both military and civil aircraft, and the largest aerospace company in the world. Its main commercial production plants are located in Seattle (WA) and Long Beach (CA). The first location represented some 60,000 (or 75 per cent) of Boeing's commercial airplane division in 2001.

Boeing is somewhat different from other prime contractors, so far as, for decades, it internalized most of its main structural parts. One indication of the vertical integration of Boeing is the high percentage of aerospace employees in its two major locations. In each case, Boeing represents over 80 per cent. Engines from its six different models come from all producers: GE and P&W in the USA, but also Rolls-Royce in the UK and CFM-SNECMA in France. Avionics are supplied most often by Honeywell (USA) and BAE Systems (UK).

The fact is that Boeing has probably produced less international (as well as inter-regional and regional) spillovers than the other major aerospace producers. But the 2001 crisis forced Boeing to accelerate its vertical disintegration and look for foreign partners and foreign locations in order to increase market penetration, as well as to reduce design and production costs.

3.4. Knowledge Spillovers in Aerospace

As the previous descriptions suggest, most prime contractors design products, then call for tenders among tier 2 suppliers across the world and send them their designs and requirements. These tier 2 producers make technical and commercial proposals to the OEM, and the latter proceeds to a selection of partners/suppliers. In many cases, detailed engineering is left to the tier 2 producers, but increasingly often international collaboration and associated massive knowledge flows occur between tier 1, 2 and 3 firms, while local spillovers are less important in quantity and strategic value and relate tier 4 firms with OEMs in the upper tiers. More often than not, final aircraft assembling occurs in one region (typically Hamburg and Toulouse for Airbus, Seattle for Boeing, and Montreal for Bombardier), engine assembly in another (Bristol for Rolls-Royce, Hartford, Connecticut and Montreal for P&W, Evendale, Ohio or Lynn, Massachusetts for GE), yet critical parts such as avionics, landing gear or nacelles are produced somewhere else. Four characteristics appear when these knowledge flows are examined. First, they are mostly international. Second, they are mostly constituted of explicit and codified knowledge. Third, they involve several independent companies. And finally, they are closely tied to markets for parts, components and subassemblies.

We studied Bombardier Engineering System in some detail. The prime contractor transmits its technical requirement documents for each new product to its supplying partners, and they in turn send back their technical and commercial proposals to respond to Bombardier's demands. Once Bombardier chooses its final partners, work starts often for co-development (detailed engineering) of the major subassemblies such as fuselage parts, wings, landing gear and avionics. Bombardier will decide the delivery schedules, quality requirements, performance and other characteristics of the different sections it buys, with the exception of engines. The large assembler is also responsible for the certification of the new aircraft, again with the exception of engines, which are certified independently by the producers (such as GE, P&W, Rolls-Royce, Honeywell or the smaller European producers such as SNECMA in France). The large assembler generates most knowledge and transmits it to its partners/suppliers. International knowledge spillovers and markets for components are created in this way. These spillovers may serve Bombardier's suppliers to address the demands of other aircraft producers.

As for Boeing, the comparison of the official list of over 400 suppliers with that of tier 2 and 3 manufacturers in the Seattle region shows that only a handful of Boeing suppliers have facilities in the area. Most major parts of Boeing's commercial aircrafts are acquired from other regions of the USA, and increasingly often, from abroad.

In Brazil, 95 per cent of Embraer's suppliers are located abroad. International suppliers are responsible for over 60 per cent of final cost (and 38 per cent of final cost is represented by Embraer), thus providing an indicator of the reduced importance of local knowledge flows (Cassiolato *et al.* 2002).

In an in-depth analysis about the impact of offset agreements on the future development of US commercial aircraft production, MacPherson and Pritchard (2003) have revealed the extreme importance of this mechanism for the international transfer of technology and knowledge spillovers. Acting as an intensive conduit for technology transfer, this practice has created new competitors or/and reinforced old ones. The authors argue that key segments of the US commercial aircraft industry are facing the risk of quitting the market. Table 5 shows the progress of foreign producers' participation in the manufacturing of different Boeing airframes, during the period 1963–94.

4. Back to Theory

A substantial literature on regional innovation systems, clusters and local agglomeration of firms has emphasized the many factors that make face-to-face transmission of knowledge, thus local knowledge spillovers, preferable to international or even national ones. The tacit element of knowledge can be more easily transmitted without distortion in local communication. The transmission of knowledge is also cheaper within regions than between regions. Finally, more channels of local knowledge transfer (such as conferences, participation in local associations, face-to-face meetings, etc.) are available than between regions, where the transmission of papers, telephone and other electronic communication are pervasive.

Table 5. Boeing's airframe production by source

Launch year Aircraft model	1963 727	1966 737	1969 747	1981 757	1982 767	1994 777
Wings	D	D	D	D	D	D
Inboard flaps	D	F	F	F	F	D
Outboard flaps	D	F	F	F	F	F
Engine nacelles	D	D	D	D	D	D
Nose	D	D	D	D	D	D
Engine strut	D	D	F	D	D	D
Front fuselage	D	D	D	F/D	F	F
Centre fuselage	D	D	D	F/D	F	F
Centre wing box	D	D	F	D	D	F
Keel beam	D	D	D	D	D	F
Aft fuselage	D	D	D	D	F	F
Stabilizer	D	F/D	D	D	F	D
Dorsal fin	D	D	D	F	F	F
Vertical fin	D	F/D	D	D	F	D
Elevators	D	F	D	F	F	F
Rudder	D	F	D	F	F	F
Passenger doors	D	D	D	D	F	F
Cargo doors	D	D	F	F	F	F
Section 48	D	F/D	F/D	D	F	F
No. of major parts from foreign sources	0	7	6	8	13	12

D=domestic production; F=foreign production; F/D=shared production.
Source: MacPherson and Pritchard (2003).

However, an important literature has also emphasized the existence and frequency of international knowledge spillovers (Gong and Keller 2003). These externalities occur through international trade, international direct investment, international technology transfer, and alliances or acquisitions. We have observed all these types of channels at work in the aerospace industry, as Table 6 shows.

We hypothesize that the aerospace industry—even if it is a science-based one by any standard—is a century-old activity in which knowledge has become fairly codified and can be transmitted on electronic and printed support without difficulty. Most of the literature on local spillovers is based either on traditional industries in which tacit knowledge is pervasive (such as glass-making, shoe or ceramic manufacturing in Italy) or on high-technology new industries in which much knowledge is not yet codified (such as biotechnology) (Table 7).

International knowledge spillovers mostly occur between tier 1 and 2 manufacturers, usually large corporations. Conversely, local knowledge spillovers, and aerospace clusters, are based on geographically close

Table 6. Channels for international knowledge spillovers in aerospace

Type of channel	Authors	Hard evidence	Examples
Foreign direct investment and international consortia	Baldwin *et al.* (1999), Xu (2000), Girma and Watelin (2001), Gong and Keller (2003)	Close to 50 percent of Canadian industry assets are under foreign control. Increasing number of European aerospace consortia	Bell Helicopter Canada, Goodrich Canada, Honeywell Canada, Messier-Dowty, P&WC, Rolls-Royce Plc in Canada. Airbus, ATR and EADS in Europe
International trade of parts, supply chain management, international transfer of aircraft and parts design	Coe and Helpman (1995), Gostic (1998), Prudente (1999)	Exports represent well over 70 percent of Canadian aerospace industry revenue. Imports are in the 70 percent range	Bombardier through BES, Héroux-Devtek, Honeywell Canada, P&WC
International alliances for co-development, international acquisitions	Mowery (1987), Dussauge (1990), Dussauge and Garrette (1995)	Numerous major cases of co-development within and outside the supply chain	Bombardier/Mitsubishi for structures, P&WC/MBU for engines, Bombardier/Learjet, Bombardier/Short Brothers

relationships between tier 2, 3 and 4 producers. The latter, usually SMEs, manufacture pieces and parts for the tier 2 and 3 subassemblers, the products of which may then be exported to other locations for final assembly in aircraft by tier 1 OEMs. Aerospace clusters are places where most knowledge transferred is not strategic (such as designs of aircraft metal parts, fasteners, seats, carpets and paints and their manufacturing techniques) but usually gathers hundreds of SMEs around one or several tier 1 and 2 assemblers into a specific metropolitan area.

5. Conclusion

Our two research questions, based on theoretical literatures, obtain clear responses. Aerospace clusters show many industry-specific characteristics when compared with automobile, biotechnology and information technology regional innovation systems. Specifically, aerospace clusters display strong international connections rather than local ones; also, the materials exchange within the cluster (often measured by input–output matrix) tends to disappear as international outsourcing of large subassemblies looms larger in the product life cycle strategy of firms. Also, anchor firms remain at the centre of the cluster, surrounded by scores of small and medium-sized

Table 7. Knowledge spillovers and flows in aerospace and biotechnology

Variable	Aerospace	Biotechnology
The main sources of knowledge spillovers	Large designers and final assemblers	Universities, venture capital firms and government labs
The main spillover beneficiaries	Tier 2 and 3 firms	Entrepreneurial SBFs
Nature of knowledge externalities	Codified knowledge on supply chain management: designs, tech specs, TQC, JIT, manufacturing blueprints	Codified (publication and patent) and personal knowledge on biotech products and processes, on financing and management
Most frequent geographical dimension of knowledge externalities	International (companies in different countries)	Local, regional and national (companies and institutions in the area)
Number of personnel involved in typical spillover	Thousands	Dozens
Duration of spillover processes	Years	Years
Level of organization of knowledge flows	Highly structured by major firms, and linked to markets	Spontaneous, and less structured with technology markets emerging
Hierarchy of flows	High	Low
Amount of knowledge flowing	Massive, due to complex products (thousands of documents per product)	Scattered (a few articles/ patents per flow)

producers of those parts and components used by the remaining OEMs within the region. The following conclusions may as well be drawn.

First, large firms dominate aerospace clusters and represent a magnet for suppliers. Originally these were Perroux clusters, but as markets for subassemblies became international, they are now Marshallian industrial districts more than anything else: today large successful assemblers "attract" scores of other firms to the clusters through the creation of a large labour pool of skilled workers. Porter's theories do not easily apply to this type of cluster. Dynamic factors in Porter's model do not correspond to these agglomerations: there is neither local inter-firm competition, nor local demand. Aircraft are world products, and inter-firm competition takes place around the globe, not within the cluster. These are anchor-firm industrial districts in one specific sense: large OEMs create some economies of specialization and more often labour market economies. In these former Perroux clusters, suppliers were attracted with the prospect of selling parts and components to the local OEM. Progressively, however, these suppliers

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may have diversified their markets in order to reduce their dependence on one major client.

Second, in aerospace production clusters and innovation clusters may not overlap. Products may be designed in one place and produced in other areas as is the case for Montreal's civil helicopters and Long Beach-produced Boeing 777 designed in Seattle. This other type of international and inter-regional knowledge spillover is frequent in aerospace.

Third, in aerospace the role of universities and government laboratories is secondary. They may appear late or not appear at all within the regional system. Aerospace corporations may attract these institutions (i.e. the new NRC laboratory being attracted to Montreal), or change them (i.e. new aerospace graduate programs and research in Montreal created decades after the establishment of the regional system), contrary to biotechnology, where universities often incubated the private firms.

Fourth, inertia due to large sunk costs in major manufacturing plants makes aerospace clusters long-term phenomena. Aerospace clusters are usually everlasting elements of the regional landscape. Thus most aerospace clusters are reconverted from the design and assembly of entire aircraft to the production of subassemblies for more successful producers (cases of Belfast for Bombardier, Lancashire for Airbus and Boeing, Long Beach for Boeing). These conversions also generate major international or inter-regional knowledge externalities.

Fifth, regional knowledge spillovers are variable, depending on the local importance of the supply chain. Most often, regional knowledge externalities are fairly reduced, due to the fact that most of the planes are assembled with components provided by overseas manufacturers. Also, university and government laboratories produce few regional spillovers in aerospace where the bulk of the new productive knowledge is produced within the firms. Thus, there is room for scepticism, as Breschi and Lissoni (2001) have suggested, about the ubiquity of regional knowledge spillovers in high-technology clusters.

Finally, clusters and regional innovation systems tend to be formed by one or two large tier 1 OEMs and/or tier 2 producers, surrounded by hundreds of small and medium-sized producers of parts and components. In spite of strong regional concentration, new poles are growing in the emerging markets of Latin America (Brazil) and South East Asia, based on increasing manufacturing capabilities and the use of market leverage to attract international production.

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