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The long-term evolution of vertically-related industries

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The long term evolution of vertically-related industries*.

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Abstract

The paper develops the argument that the long-term structural evolution of an industry depends on the evolution of a vertically-related, downstream industry. We analyse two pairs of vertically-related industries, the jet and turboprop aircraft and engine industries, since the first introduction of the jet and turboprop technologies to 1998. The paper shows that the evolutionary dynamics of the downstream industry, in terms of number of firms and products, entry, exit and concentration, is transmitted to the upstream industry via the structure of the *network* of vertical exchange relations. We identify two network configurations, *partitioned and hierarchical*, and show that they are responsible for sharply different transmission effects. An econometric analysis is carried out to demonstrate this difference in the turboprop and jet markets.

JEL classification: L13, L19, L22, L62

Key words: vertically-related industries; network; industrial concentration; entry; exit.

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1. Introduction

This paper develops the argument that the long term structural evolution of an industry depends, in predictable ways, on the evolution of a vertically-related, downstream industry. More precisely, the evolutionary dynamics of the downstream industry, in terms of number of firms and products, entry, exit and concentration, is transmitted to the upstream industry via the structure of the network of vertical exchange relations.

The claim that the vertical structure of an industry is a determinant of its concentration has been made repeatedly in the literature. At an aggregate level, the countervailing power theory posits a simple relation between concentration indexes in the two industries, without specifying the micro-mechanisms that transmit the effects[1]. At a micro level, both theories of vertical integration based on contracts and industrial organisation theories of sourcing decisions, switching costs and compatibility among systems and components, derive optimal vertical configurations. However, they are rather silent on the aggregate effect on concentration and, moreover, on the dynamics of the vertical configuration over time[2]. It seems that there is a need for an approach that explicitly links individual exchange decisions between buyers and sellers in two vertically-related industries with the aggregate dynamics. Recently, industry studies and evolutionary models have emphasised that patterns of vertical integration and of division of labour are powerful engines of change of the industry structure[3].

We develop an original approach which is based on a construct, the network of vertical relations between individual firms in buyer and supplier industries. The formation and evolution of the network is explained through technology and market factors such as the level of economies of scope, the degree of technological co-specialisation between products in the upstream and downstream industries, the buyers' sourcing strategies and the degree of market fragmentation.

There are a number of advantages in adopting a network approach to the study of coevolution of vertically related industries. First, the unit of analysis is the single transaction, but it is not isolated from all other transactions taking place in the industry. As Holmstrom and Roberts (1998) pointed out, "in market networks, interdependencies are more than bilateral, and how one organises one set of transactions depends on how the other transactions are set up". Second, specific factors featuring vertical relations such as degree of asset specificity, technological complementarities, frequency of relations, or pattern of sourcing, are carefully reflected in several network measures at the transaction level, at the firm level (buyer and supplier), and at the overall network level. For example, the

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[1] For some references see Galbraith, 1952; Bain, 1968; Lustgarten, 1975; LaFrance, 1979; Scherer, 1980; von Ungern-Sternberg, 1996.

[2] Among others, see Williamson, 1985, 1999; Klein et al., 1978; Monteverde and Teece, 1982; Hart and Tirole, 1990; Riordan, 1998; Demsky et al., 1987; Riordan and Sappington, 1989; Klemperer, 1997; Farrell et al., 1998.

[3] See Arora and Gambardella, 1998; Malerba et al. 1998; Bresnahan and Greenstein, 1999; Bresnahan and Malerba, 1999; Langlois and Steinmueller, 1999.

adoption of single or multiple sourcing strategies is represented by the number of relations for buyers. Diffuse adoption of multiple sourcing leads to a dense network, while single sourcing shapes a less dense network, which is also partitioned if the supplier industry is not monopolistic. Third, the relationship between the dynamics of vertical relations and industrial dynamics can be studied through the analysis of the relationship between variables describing upstream and downstream industries, i.e. level of concentration, dynamics of market shares, entry and exit, and variables describing the network.

This paper analyses two pairs of vertically-related industries, the commercial jet aircraft and engine industries, and the commercial turboprop aircraft and engine industries, since the first introduction of the jet (1958) and turboprop (1948) technologies to 1998.

Turboprop and jet engine industries exhibit different structural dynamics with respect to the pattern of entry and exit of firms and products and the level of industry concentration. We study the evolution of the upstream industry by looking at the evolution of the downstream industry, and make the argument that the transmission of effects from one industry to the other is determined by the structure of the network linking the two.

Technological and market factors shape the emergence of different structures of vertical networks in the jet and turboprop industries. We identify two basic configurations, partitioned and hierarchical, and show how different network configurations in the jet and in the turboprop are responsible for sharply different transmission mechanisms of the changes of the downstream to the upstream industry.

An econometric analysis is developed to test some hypotheses on the transmission mechanisms in the two pairs of industries.

2. Industrial dynamics

After the Second World War the commercial aircraft industry was characterised by the transition from the piston to the gas turbine engine propulsion technology, transition already experienced during the War by the military industry. Two different technological solutions, the turbojet an the turboprop, emerged and developed along two different technological trajectories. While at the beginning competition between turbojet and turboprop occurred especially in one segment of the market (aircraft with 51-90 seats), over time the markets with smaller seat capacity have been dominated by the turboprops, while the markets with larger seat capacity (91-120 to more than 400 seats) by the jet. The divergence of technological trajectories originated markedly different market applications (large commercial aircraft and aircraft for regional transport) and led to the birth of independent segments of the industry. In fact, out of 12 engine manufacturers only 4 operated in both the jet and the turboprop. On the demand side the two industries are completely separated, insofar as no aircraft manufacturers operated in both markets. The only partial overlapping between the two industries took place when some firms from the turboprop have been entering the small regional jet segment of the market in the 1990s. As a matter of fact, we are dealing with two pairs of vertically-related industries which can be considered as independent on each other, with regards to specific determinants of industrial dynamics, although there may be correlation in external factors influencing both of them (e.g. trend in transportation demand).

This paper analyses a case of vertically-related industries, i.e. a supplier industry which sells only to one downstream industry, which in turn cannot substitute the products with those of competing sectors. Aircraft and engine industries, in both jet and turboprop, are characterised by a stable pattern of vertical separation, insofar as vertical integration of engine production never occurred over the entire history of these industries[4]. There is also no diversification, either in market demand for the upstream industry, or in supply sources for the downstream one. Of course, there is still the possibility that the survival of firms is subsidised by military sales or government interventions. Although this applies to specific circumstances, it is difficult to accept as an explanation of long term evolution[5].

The study is developed as follows. This section describes three basic industry variables - i.e. number of firms, concentration and introduction of new products - and shows sharp differences in the jet and turboprop vertically-related industries[6]. The structural dynamics of the industry highlights some relevant stylised facts with respect to the pattern of *entry and exit of vertically-related firms and products*. Section 3 examines in depth the *structural dynamics of the networks* connecting vertically related industries. Finally in section 4 we develop an econometric model to test the hypothesis that the *relation between upstream and downstream industry variables depends on the structure of the network.*

Figure 1 shows the evolution of the *number of firms* and the *entry and exit* events in the four industries. The graph clearly reveals a similarity in the evolution of the number of firms in the

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[4] There are not specific studies addressing vertical integration of the engine industry. Technological bases are entirely different in the engine and aircraft industries, the costs of development of engines and aircraft are huge and excess correlation of risk has been considered a reason for vertical separation (Klein, 1977).

[5] Although economies of scope are clearly relevant in R&D, commercial engines are developed for being integrated into commercial aircraft, with no easy cross-over with military products. Moreover, in the cross country distribution of aircraft-engine relations, we do not observe any specialisation of supply relations by country; that is, aircraft manufacturers did not necessarily buy engines from national suppliers. On the contrary, global sourcing strategies have occurred since the beginning of the industry. The history of the supply relations offered many examples of the interrelations between US and European engine and aircraft companies: Pratt & Whitney supplied Sud Aviation, while Rolls Royce powered some Boeing and Douglas aircraft by the 1960s; Airbus aircraft have been mostly powered by General Electric and Pratt & Whitney engines.

[6] The description of the data is reported in Appendix 1.

turboprop engine and aircraft industries, while different dynamics characterise the jet aircraft and engine industries[7].

The history of the relations between entry and exit events of aircraft and engine manufacturers highlights some interesting stylised facts. In the turboprop market we observe that:

– New aircraft manufacturers are either served by existing or new suppliers.

– Entry of engine suppliers always occurs to serve new aircraft customers[8].

– New aircraft programs introduced by existing customers are generally powered by the established engine supplier, unless the new program is introduced in a different segment of the market which is not served by the existing supplier.

– Minor engine manufacturers are induced to leave the industry by the exit of their main customer[9].

By contrast, the jet market is characterised by the following facts:

– New aircraft manufacturers are always served by existing engine suppliers (the only exception is the entry of Embraer supplied by the new entrant Allison in the segment of the small regional jets).

– Engine manufacturers do not enter to supply new, but existing aircraft manufacturers (except the case of Embraer and Allison mentioned above).

– There is no established pattern for the choice of the engine supplying the launch of a program by an existing aircraft manufacturers.

– As no exit of engine manufacturers occurs during all the history, there is no relation with the exit of aircraft companies.

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[7] It is interesting to note that the patterns observed in the two engine industries are different from the patterns predicted and explained by different streams of research on the dynamics of industry population (Klepper, 1996, 1997; Hannan and Carroll, 1992; Carroll and Hannan, 2000). Explanations of the diversity have been proposed in Bonaccorsi and Giuri (2000a) for the turboprop and in Bonaccorsi and Giuri (2000b) for the jet.

[8] After the first flight of the Vickers Viscount in 1948 and of the Fokker F27 in 1955, powered by the Rolls Royce Dart, in 1957 Allison enters to power the Lockheed L-188 Electra. In 1963 the aircraft manufacturer Nord Aviation enters the market, supplied by Turbomeca. In 1965 Pratt & Whitney and General Electric supply two different aircraft programs introduced by the entrant de Havilland Canada. With the exception of the Czech manufacturer Walter**,** who enters to substitute Pratt & Whitney for powering the Polish Let 41, all the other engine manufacturers enter by supplying new entrants in the aircraft industry: Pilatus and Lycoming in 1973, Casa and Garrett in 1974, Yunshui and Dongan in 1984, IPTN and Allison in 1995.

[9] This is the case of Allison and Lockheed in 1969, Turbomeca and Nord Aviation in 1976, Walter and Let in 1995, and Lycoming and Pilatus in 1996. Note that these firms were not owned by aircraft manufacturers but were independent, privately-hold companies. On the contrary Rolls Royce, the leader of the market for many years, progressively lost market shares and left the industry after the exit of its former customers. The last supply relation gained by Rolls Royce was Fairchild in 1968. After the financial crisis of the 1970s, Rolls Royce concentrated its efforts only in the jet market and did not introduce new products in the turboprop industry. This caused its exit from the market in 1988.

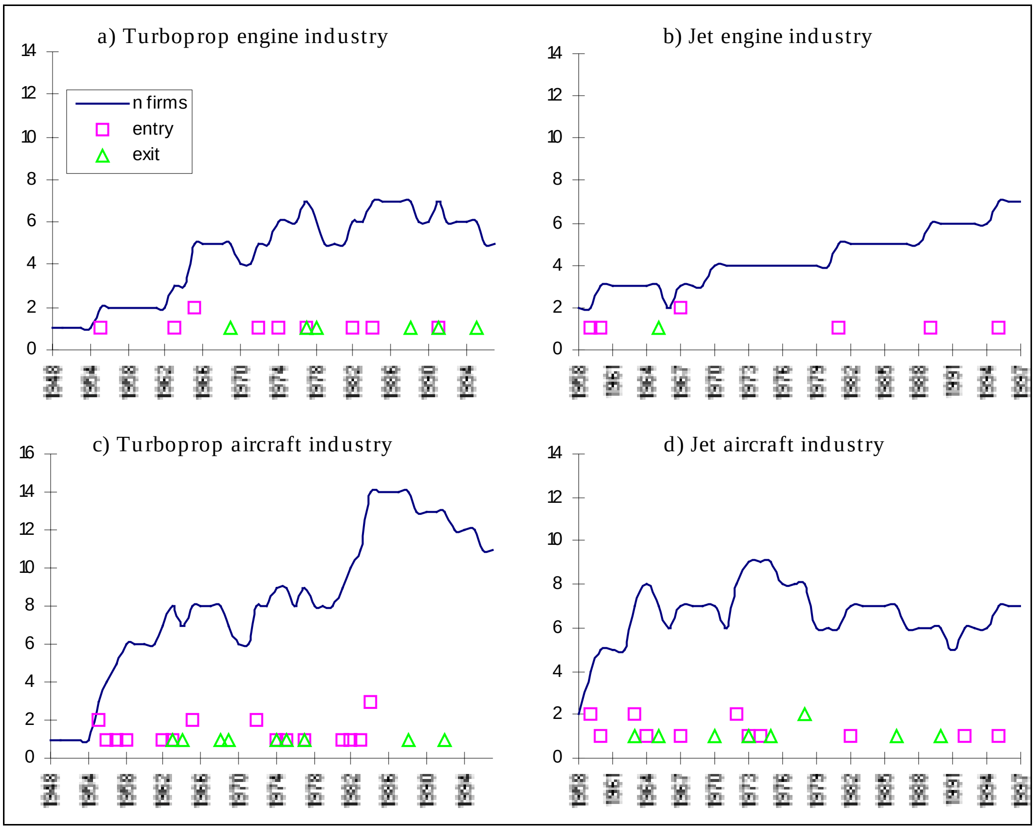

Figure 1. Number of firms, entries and exits.

Figure 2 displays the evolution of the number of products and the introduction of new products in the four industries analysed[10]. The pattern of introduction of products in the two pairs of industries is explained by the following observations.

In the turboprop engine industry, more than 55 % of the engine versions are introduced to power a single aircraft program version. About 40 % of the engine versions power a few, in most cases two or three, versions of the same aircraft program. Only 5 engines power more than one aircraft program of different aircraft manufacturers in the same segment of the market.

In the turboprop aircraft industry most of the aircraft, 109 out of 129, are powered by only one engine version, while a small number of aircraft integrate two versions of the same engine program.

In the jet engine industry we may observe three differentiated patterns. A number of engines power only one aircraft version. This is the case of engines powering aircraft for niche markets[11] and the case of the *last generation* engines, which are developed in many versions to power the same aircraft

[10] Our data on engine and aircraft products make a distinction between the program and the different versions of the same program. For example, the B777 is a program while the B777-100A, B777-100B, B777-200 are versions. A program is based on a core technology platform, while several versions are developed on the same platform by modifying design parameters. In the jet engine technology, a program is launched around a new turbine, while variations in the propulsion system may lead to several versions. The graphs show the number of versions, because programs are used for many applications through the development of different versions. The version is therefore the more fine grained innovative output of firms.

model, in order to satisfy the need of aircraft manufacturers to offer different operating conditions required by airlines[12]. Other engines are integrated in different models and versions of the same program. Finally, several engines of the *first and second generation* are integrated in many versions and programs of different aircraft manufacturers[13].

An inverse pattern may be noticed in the aircraft industry. Many different versions of the *first generation* of aircraft (B707, B720, DC-8, DC-9 and Caravelle) have been powered by only one engi ne version. The same pattern was found for the regional aircraft (Fokker, BAe 146, Canadair Regional Jet). Many aircraft of the *second generation* (B727, B737, B747, MD-80) integrated a number of versions of the same engine program, while the aircraft of the *third generation* (Airbus A300-600, A319, A320, A330, B757, B767, B777) are introduced in multiple sourcing. Each aircraft integrates different versions of programs of different aircraft manufacturers. As an example, each version of the B777 integrated several versions of General Electric, Pratt & Whitney and Rolls Royce engines.

In summary, the pattern observed in turboprop suggests the existence of close technological complementarity between engines and aircraft, which induces the introduction of new engines in correspondence with launch of new aircraft. In the jet, aircraft and engines of different generations are designed to operate in many seat-range conditions.

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[11] They are the Rolls Royce M45 which powered the VFW614 in the regional market, the Olympus 593 which powered the Concorde.

[12] Examples are a number of versions of the Trent, the PW 4000 series, the IA V2500 series.

[13] To name some examples, in the 1960s the Pratt & Whitney JT3D-3B has been integrated in 38 versions of the B707, B720 and DC-8, the JT8D-7 in 18 versions of the Caravelle, B727, B737 and DC-9, while in the 1980s and the 1990s the General Electric CF6-80C2 has powered 22 versions of the A300, A310, B747, B767 and MD-11.

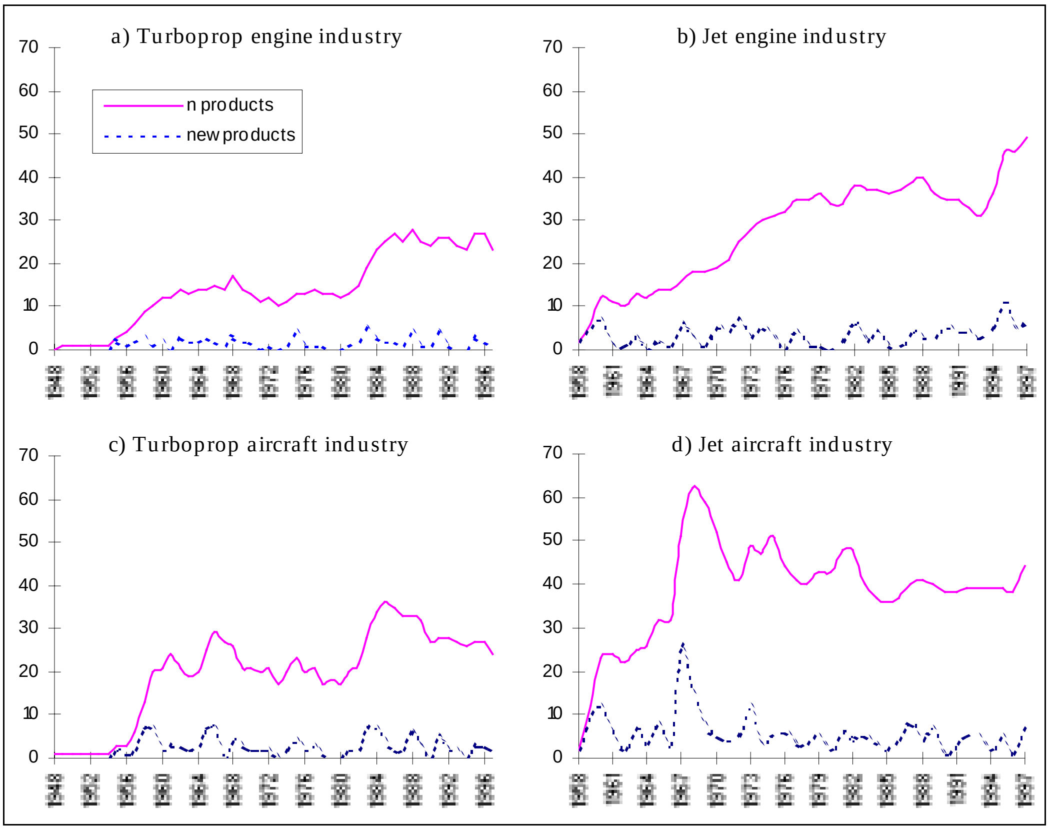

Figure 2. Total number of products and introduction of new products

Finally, comparing *the level of concentration* in the engine and aircraft industries we may observe that, although the processes of concentration are different in the four industries, the dynamics of the two pairs of vertically-related industries are similar over time. In the turboprop they show simultaneous increasing and decreasing patterns, in the jet they show a declining pattern, but characterised by different speed of change and competitive dynamics among major players.

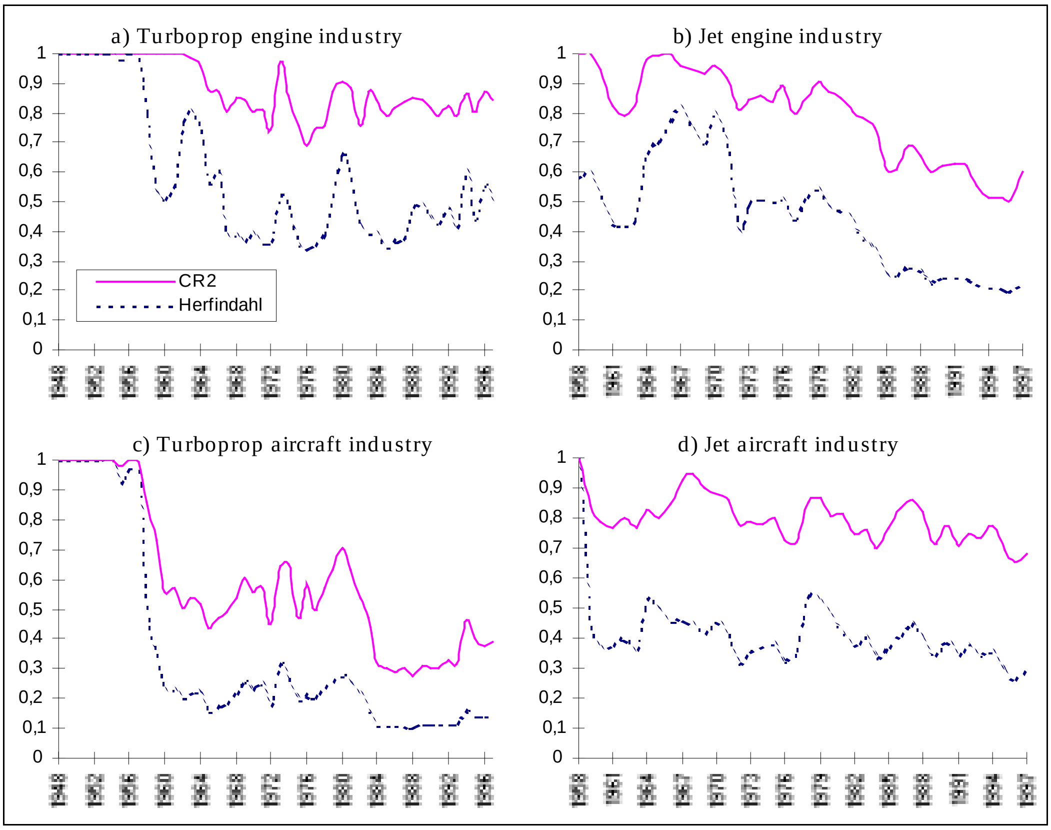

Figure 3. Level of industrial concentration

3. The structure and dynamics of the network

3.1. Networks

In order to explain the surprising difference in the way the structural dynamics of two pairs of industries are related, we suggest to examine the properties of the network of vertical exchanges which connects them.

Network analysis has been applied in many fields of social sciences, including economics, sociology, and organisation, for analysing different structures of interactions among agents (individuals, firms, groups of actors, technical artefacts). In the analysis of industries, network concepts and techniques are increasingly used in the field of inter-firm agreements (joint ventures, licensing, technological alliances, consortia and the like) (Powell, 1996; Orsenigo et al, 1998, 2000). We apply network analysis to the study of vertical relations between buyers and suppliers.

The unit of analysis is the transaction of engines occurring between an engine and an aircraft manufacturer each year. Relations are characterised by high frequency and stability. The yearly average number of transactions of each relation is 85 in the jet and 37 in the turboprop, while the minimum and the maximum are respectively 11 and 436 in the jet and 3.33 and 132 in the turboprop. The range of variation depends on the market shares of the companies and on the size of the market segment. Relations are also very stable over time. In fact interruptions of relations are very rare, with the exception of cases of exit of actors, while new relations tend to be added to the existing and to persist over time. The total number of relations which compose a network depends on entry and exit of actors, and on creation and interruption of relations. The stability of the relations implies that the structural configuration of the network is persistent over time, and it is not subject to short run changes, and the way relations are distributed among actors is not random, but depends on structural factors of the industries under study.

The network may assume different topologies which can be represented by different network measures. For the purposes of this study, we analyse three structural properties of the network: the *relational intensity*, the *distribution* of the relations across actors and the *separability* of the network.

For the analysis of vertically-related industries we study bipartite graphs, in which edges connect vertices from different sets of actors (buyers and suppliers) and there are no ties within each set (Borgatti and Everett, 1997; Asratian et al., 1999). The edges in the network are determined by the order of an engine placed by an aircraft company to an aero-engine manufacturer at a given date. The structure of the relations is represented for each year by a biadjacency matrix, whose cells represent the binary variable "a relation exists / does not exist".

We selected the following network measures to study the structural properties of the network: density, *k*-core, cut-points and bi-components.

The *density* is essentially a count of the number of edges actually present in a graph, divided by the maximum possible number of edges in a graph of the same size. Density is a synthetic measure of network structure which provides information about the group *relational intensity* and the cohesion of a graph, but does not include information about the variability among actor degrees.

We also calculate measures at the sub-graph level, to analyse the *distribution of the relations* across actors. In particular we study the number and size of *k*-cores, which give a clear representation of the presence of cohesive sub-groups. A *k*-core is a connected maximal induced sub-graph which has minimum degree greater than or equal to *k* (Wasserman and Faust, 1995). The degree of an actor is the number of edges incident with that vertex. Each member of a *k*-core is related to at least *k* other actors on the other set. We calculate the number of *k*-cores in the jet and turboprop networks for every possible value of *k* and for each year of their life. For k=1 the number of cores indicates the degree of *partition* of a network. The higher the number, the higher the degree of partition of the network, as the network can be separated in *n* sub-graphs without deleting any vertex. The presence of cores with degree greater than or equal to *k* denotes cohesiveness of a graph, that is the distribution of relations across actors is not dispersed but is concentrated in sub-groups of intensely connected actors. In particular, a network characterised by a restricted core and a periphery of disconnected actors can be defined as *hierarchical*.

The *separability* of the network is finally analysed through the number of bi-components and cut-points of the graphs. A *bi-component* (or block) of a graph is a maximally non-separable sub-graph. It requires deletion of at least two vertices to disconnect it. A *cut-point* is a node which is connected to more than one bi-components, therefore its deletion disconnects the graph.

The number of bi-components and cut-points provides an indication of the connectivity of a graph. The higher its number, the higher the probability that a graph will be disconnected for the deletion of a vertex, that is for the interruption of a relation or the exit of a player. The size of the bi-components, similarly to the analysis of *k*-cores, gives an indication of the size of highly connected sub-groups. Precisely, bi-components with more than two actors correspond to *k*-cores with *k* greater than 1[14].

3.2. Networks in turboprop and jet industries

Figures 4 and 5 exhibit pictures of the network structure in the turboprop and jet markets at 4 points in time, while table 1 summarises the network measures at the group and sub-group level for each year of the period. The measures computed are number of actors (*actors*), level of relational density of the network (*density*), number of *k*-cores with *k*=1 (*1-core*), number of *k*-cores with *k*=2 (*2-core*), number of vertices in the core with k=2 (*2-core size*), number of bi-components (*bi-comp*), number of actors presents in more than one bi-component (*cutpoints*).

At the aggregate level, we observe that the level of density in the jet is higher than in the turboprop, which indicates higher relational intensity among buyers and suppliers.

[14] Measures of *k*-cores, bi-components and cut-points are computed by using the software Ucinet 5 (Borgatti et al., 1999).

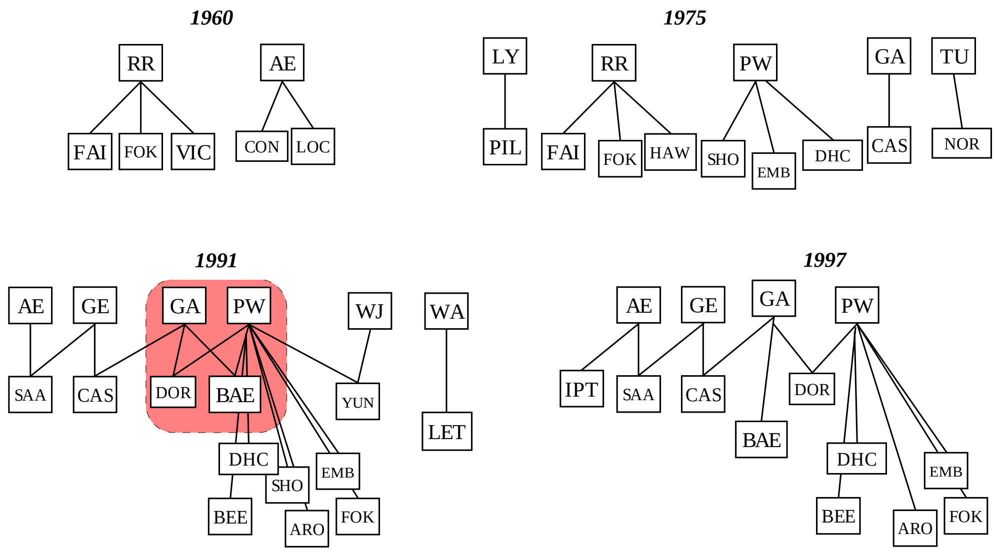

Figure 4. The turboprop network

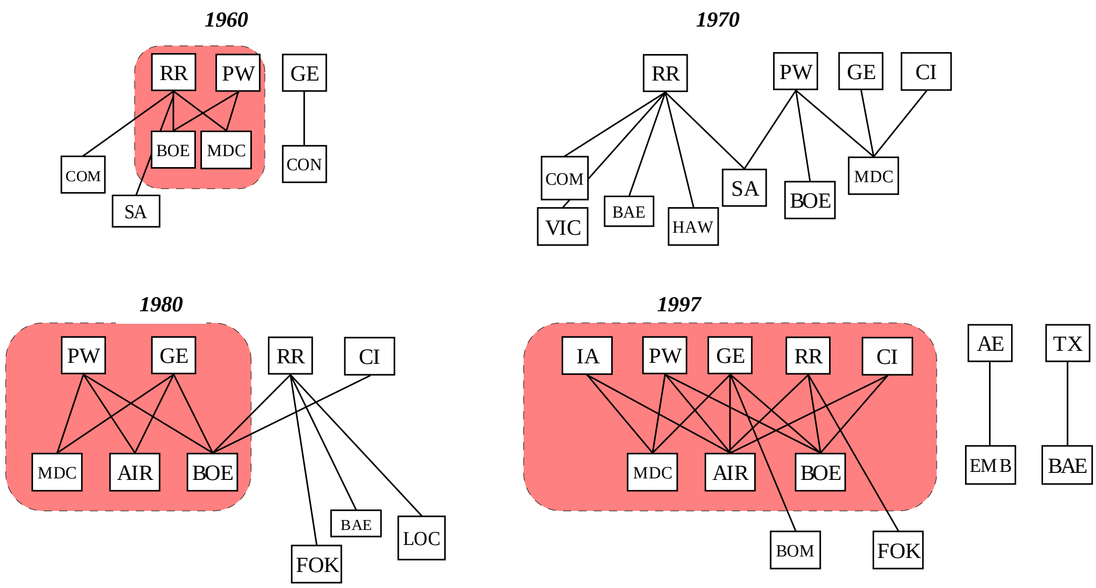

Figure 5. The jet network

The analysis at the sub-graph level provides details on the distribution of relations across sub-groups of actors. In particular, it gives evidence of the degree of partition and of the formation of a hierarchical structure of the network.

The degree of partition of the network in the jet is lower than in the turboprop as the number of *k*-cores with degree equal to 1 is smaller. In the turboprop network the number of *1*-cores increases over time and ranges between 3 and 6 for a large portion of the time, although it tends to decrease over the last years of the industry evolution. In 1975 there are five partitions while in 1997 there is only one partition, as there are not completely separated sub-graphs. In the jet, the network is composed of only 1 or 2 sub-graphs over all its life, except in the last three years, in which there are three *1*-cores. The larger partition is composed of 10 actors in the market for large commercial aircraft. The other two partitions are two pairs of vertically-related firms in the market for small regional jets.

The number of 2-cores denotes the degree of hierarchisation of the network. The network of the jet assumes a *hierarchical* configuration as it is possible to identify a cohesive core in which the actors have degree greater than or equal to 2. The core emerged during the first stage of the industry life and was initially composed of 4 actors (shaded area in figure 5, 1960). The entry of new actors at the end of the 1960s and at the beginning of the 1970s destabilised the network and the core. The intensification of the relational activities of entrants and incumbents led again to the emergence of a core which expanded during the industry evolution. In fact, as evident from the table, the number of actors grew from 4 in 1975 to 8 in 1997, therefore a larger part of actors entered the core. The core was composed of the incumbent engine suppliers and of major aircraft manufacturers operating in multiple sourcing. On the other hand, a periphery was also created in the network, which was composed of actors with degree equal to 1, that is aircraft manufacturers in single sourcing and engine suppliers in the regional market. The network was also partitioned in the last three years, as there were three subgroups, two of them in the regional market (Allison-Embraer and Textron-British Aerospace), and the other containing the *2*-core.

The network in the turboprop presents a very different structural dynamics. In fact, except for a five-year period, there are no highly connected sub-groups of actors, as indicated by the absence of *2*-cores in almost all the industry life. Only from 1991 to 1995 a 2-core was formed by four actors, but it was transitory (see figure 4, 1991). This indicates that relations among actors are exclusive and sparse, and are not concentrated around a group of actors.

Further evidence on the degree of connectivity and separability of the networks are given by the number of bi-components and cut-points. In the jet, these two variables increase until the beginning of the 1970s, when the network is destabilised by the entry of new actors. Subsequently, the indicators decline until 1997, suggesting higher connectivity of the network. In the turboprop, both the number of bi-components and cut-points grow over time, denoting lower connectivity and higher separability of the graph. The difference of the values in jet and turboprop is not very large, especially if compared with the number of actors, which is larger in the latter. This reflects the presence of turboprop engine suppliers, namely Rolls Royce and Pratt & Whitney, which are present in a high number of bi-components. Precisely during the 1970s the number of cut-points is very low, compared to the number of bi-components, because many aircraft manufacturers in single sourcing are supplied by only two engine companies. During the 1980s and 1990s, although the number of bi-components in which Pratt

& Whitney is active is still high, the number of cut-points grows, denoting the increasing separability of the network through other nodes.

Combining these results, we observe a *partitioned structure* of the turboprop network and a *hierarchical structure* of the jet network.

Table 1. Density, *k*-cores and bi-components in turboprop and jet networks

	TURBOPROP							**JET**						
	actors	*density*	*1-core*	*2-core*	*size 2-core*	*bi-comp*	*cut-points*	*actors*	*density*	*1-core*	*2-core*	*size 2-core*	*bi-comp*	*cut-points*
1953	2	1,00	1	-	-	1	0							
1954	2	1,00	1	-	-	1	0							
1955	5	0,50	2	-	-	3	1							
1956	6	1,00	1	-	-	2	1							
1957	7	0,50	2	-	-	3	1							
1958	8	0,50	2	-	-	5	1	4	0,5	2	-	-	2	0
1959	8	0,50	2	-	-	5	1	6	0,5	2	-	-	4	2
1960	8	0,50	2	-	-	5	2	8	0,47	2	1	4	4	1
1961	8	0,50	2	-	-	6	2	8	0,47	2	1	4	4	1
1962	9	0,58	2	-	-	7	2	8	0,53	2	1	5	3	1
1963	11	0,33	3	-	-	8	2	10	0,43	2	1	4	6	1
1964	10	0,38	2	-	-	8	3	11	0,42	2	1	4	7	2
1965	13	0,25	3	-	-	10	4	10	0,43	2	1	4	6	2
1966	13	0,31	2	-	-	10	5	8	0,67	1	1	4	5	2
1967	13	0,29	2	-	-	10	5	10	0,48	1	1	4	7	3
1968	13	0,28	2	-	-	11	4	10	0,43	1	1	4	6	3
1969	12	0,26	3	-	-	9	2	10	0,43	1	-	-	9	4
1970	10	0,30	3	-	-	6	2	11	0,36	1	-	-	10	4
1971	10	0,29	3	-	-	7	3	10	0,38	2	-	-	8	3
1972	13	0,23	4	-	-	9	2	12	0,36	2	-	-	10	4
1973	13	0,25	4	-	-	7	2	13	0,38	2	-	-	9	4
1974	15	0,25	4	-	-	8	2	13	0,38	2	-	-	9	2
1975	15	0,20	5	-	-	9	2	13	0,38	2	1	4	9	2
1976	14	0,21	4	-	-	10	4	12	0,42	2	1	4	7	3
1977	16	0,16	6	-	-	11	3	12	0,46	1	1	6	7	3
1978	14	0,23	4	-	-	8	3	12	0,43	1	1	4	9	2
1979	13	0,23	4	-	-	8	3	10	0,51	1	1	4	6	3
1980	13	0,29	3	-	-	7	3	10	0,52	1	1	5	7	2
1981	14	0,28	3	-	-	9	4	11	0,44	1	1	5	6	3
1982	16	0,24	3	-	-	12	5	12	0,41	1	1	5	8	3
1983	17	0,22	4	-	-	11	4	12	0,35	2	1	4	8	3
1984	21	0,16	5	-	-	12	5	12	0,44	1	1	5	7	3
1985	21	0,21	3	-	-	12	7	12	0,36	2	1	5	8	3
1986	21	0,22	2	-	-	12	7	12	0,35	2	1	4	8	3
1987	21	0,27	1	-	-	12	7	11	0,44	2	1	6	5	2
1988	21	0,22	2	-	-	12	7	11	0,49	2	1	6	4	2
1989	19	0,21	3	-	-	12	6	12	0,49	2	1	6	5	3
1990	19	0,21	3	-	-	12	6	12	0,44	2	1	6	6	3
1991	20	0,24	2	1	4	12	6	11	0,49	2	1	6	5	3
1992	19	0,22	3	1	4	12	5	12	0,44	2	1	6	6	4
1993	18	0,34	1	1	4	12	5	12	0,44	2	1	6	6	4
1994	18	0,34	1	1	4	12	5	12	0,44	2	1	6	6	4
1995	18	0,27	2	1	4	12	6	14	0,39	3	1	8	5	2
1996	16	0,25	2	-	-	12	7	14	0,39	3	1	8	5	2
1997	16	0,33	1	-	-	12	7	14	0,39	3	1	8	5	2

3.3. Causes of differing network structures

Where do different structural configurations of the network come from? What caused these different network structures to emerge?

We believe that differences in the networks structure in the two pairs of industries depends on the following structural factors: the degree of economies of scope, the sourcing strategy adopted by aircraft manufacturers, and the level of market segmentation. We summarise here the differences between jet and prop with respect to these structural factors, which have been studied in related papers (Bonaccorsi and Giuri, 1999, 2000a).

Economies of scope

We calculated some statistics on the number of versions per product to measure the degree of robustness of basic designs (programs) as an indication of the presence of *economies of scale and scope* in design and manufacturing activities of aircraft and engine companies. Robustness occurs in terms of adaptability of the basic design to different customers and to different market segments. It allows some degree of economies of scale (high commonality of parts) and scope (high product variety) on the R&D and production side and offers the possibility of enhanced learning from user experience. In fact users, working with similar platforms, can be more apt to ask for specific modifications of design. This type of design applies not only to sequential introduction of models, but also to different more or less contemporaneous versions (Rothwell and Gardiner, 1989, 1990).

We found that the average and the maximum number of versions per program in the jet is higher than in the prop, both in aircraft and engine. In addition, the number of programs in turboprop is higher than in turbojet, although the size of the market is smaller. This suggests that the turboprop market is more fragmented in different programs and that the degree of economies of scale and scope is much lower. Similar results have been observed by calculating indicators on the number of *applications* (aircraft programs and versions) per engine programs.

How did economies of scope influence the network structure?

In the presence of economies of scope, engine programs are potentially applicable to different aircraft programs of different manufacturers. This allows engine companies to relate to many buyers, and potentially to all of them. On the contrary, in the absence of economies of scope, turboprop companies may relate to a reduced number of aircraft companies. The only exception is the case of companies producing many different programs, but this would be an extremely expensive strategy which is not plausible in industries characterised by huge costs of development and large break even point.

Buyers' sourcing strategies

By single sourcing we mean that aircraft manufacturers select just one engine supplier for each new programme, possibly by asking the same manufacturer to develop several versions of the basic engine for the corresponding versions of the aircraft programme.

In the turboprop, the demand for engines takes place within an almost generalised single-sourcing strategy. Out of 22 aircraft manufacturers, 10 operate using multiple sourcing and 12 with single sourcing. Companies operating with dual sourcing still equip the aircraft program through single sourcing.

In the jet, the pattern of sourcing of aircraft manufacturers changed considerably over the industry evolution. While at the birth of the industry aircraft makers tended to operate through single sourcing, or in some cases dual sourcing for specific aircraft models, the solution of the major technical problems of the first stage of industry evolution, while reducing the degree of uncertainty, allowed designing aircraft to integrate different engine configurations. Innovation at the design level permitted the increasing interchangeability of engines on newer model aircraft (Bluestone et al., 1981). Airframes started to be built to accept any one of several turbine configurations offered. This trend led to the shift from single to dual and multiple sourcing strategies of large aircraft manufacturers. Multiple sourcing policies began to be adopted at the aircraft program level, and in some cases at the version level.

The differences in the jet and prop economies of scope and sourcing strategies suggest that in the prop there is a technological co-specialisation of engine and aircraft while in the jet aircraft products architectures are open and characterised by a standardised interface for engines. Jet engines are optimised for an envelop of operational conditions, while turboprop engines are designed for a narrow range of operational parameters.

With respect to the effects on the network structure, in the turboprop the diffusion of single sourcing at the firm, at the segment and at the program level induces a partitioned network. In the jet the shift from single and dual toward multiple sourcing strategies of major aircraft manufacturers led to the formation of connected network structures.

Market segmentation

The structure of demand for engines is represented by the aircraft manufacturers. In the turboprop market, customers operate mainly in just one segment of the market. Table 6.1 shows the distribution of companies across seat segments. Out of 22 manufacturers over the life of the industry, 12 were active in one segment, 9 in two segments, and just one in three segments. No one covered four segments, including the rapidly disappearing segment of 91-120 seats dominated by the jet technology. If we look at the final structure of the industry, out of 11 still active in 1997, again the largest part (72%) still operate in one segment. Those that operated in more than one segment developed their models at different dates, with the exception of the joint venture Aerospatiale-Alenia, which developed the ATR 42 in 1984 and the ATR 72 in 1988, following the same commonality strategy which is typical of the jet industry.

This is in sharp contrast with the pattern found in the jet aircraft industry (Sutton, 1998; Bonaccorsi, 1996), which is one of declining number of large suppliers operating simultaneously in all segments of the jet market. Since large jet aircraft manufacturers operate across all segments and plan their engine acquisition strategies in an integrated manner, they favour complete range suppliers.

As a result of this enormous pressure, all large engine suppliers operate in all market segments. The only jet engine suppliers that were able to survive in one or a few segments are those that supplied smaller jet engine manufacturers (e.g. British Aerospace or Embraer), which do not target the large transport aircraft market. On the supply side the presence of economies of scale and scope, reflected in the presence of robust designs of engines which power many aircraft configurations, supports a configuration of interdependence of sub-markets (see Sutton, 1998).

The same pressure is not found in the turboprop industry. Faced with customers that demand engines for just one aircraft size at a time, with no significant interdependence among segments, turboprop engine suppliers could survive with a limited range of products. The low level of economies of scope supports this configuration.

How does this affect the network?

Fragmented markets limit the scope for higher relational intensity across actors. Suppliers (or customers) operating in one or two segments can in practice relate to a reduced number of customers (suppliers) although the potential number of customers is higher. On the contrary, in industries characterised by interdependence of sub-markets each actor can in principle relate to actors on the other side in any segment.

4. Observing the transmission mechanism

The comparison between the two pairs of industries shows an intriguing difference. In the turboprop industry, the dynamics of the upstream industry closely parallel the dynamics of the downstream one. The turboprop aircraft industry exhibits a remarkable growth in the number of firms, a rapidly declining and then stable level of concentration, and an increasing number of products, with some oscillations. Almost the same patterns of change apply to the related engine industry.

This is not true for the jet. In the aircraft industry the number of firms is quite stable, concentration is slightly decreasing and the number of products has a peak and then declines. By contrast, a different pattern is found in the engine industry: the number of firms is always growing, concentration is sharply decreasing, and the number of products has an increasing trend.

We develop the hypothesis that the relation between the structural dynamics in the upstream and downstream industry is regulated by the structure of the network of vertical relations, that is, changes in the downstream industry are transmitted to the upstream industry with an intensity which depends on the structure of the network. In other words, our interpretation of the network as a transmission mechanism of changes from a downstream to an upstream industry is that a hierarchical network *filters* the transmission of effects, while a partitioned network transmits *directly* and entirely the effects. In a hierarchical network any change on the buyer side (entry of firms, introduction of new products, change in market shares) affects more than one supplier. On the contrary, in partitioned network a change in the buyer side is very likely to affect only one supplier.

To test these hypotheses we build three regression models in which the dependent variables (*Eng_Var*) are, in turn, concentration, number of firms and number of new products of the downstream industry, while the independent variables (*Air_Var*) are the respective indicators in the downstream industry (see Appendix 2 for the list of variables). The three regressions are carried out for the turboprop and the jet markets.

In order to test the significance of a network variable, in a modified specification we add density as an independent variable in the three regressions. We chose the more synthetic network measure, since we are interested in the explanation of the long run dynamics of the upstream industry.

The ADF test on the variables under study revealed that they are all non stationary and first order integrated, as they become stationary after one difference. We use an unrestricted Error Correction Model to test the short and long run relations between the variables. The specification of the general model is the following:

$$\Delta Eng\_Var_t = \alpha + \beta_0 \Delta Air\_Var_t + \pi_1 Eng\_Var_{t-1} + \pi_2 Air\_Var_{t-1} + \varepsilon \qquad (1)$$

This equation is a reparametrisation of an ARDL(1) process, where π_1 and π_2 are the long run parameters, and π_2 / π_1 represents the speed of adjustment towards the long run solution of the model. The test for the long run solution is based on these hypothesis:

H_0: $\pi_1=0$

H_1: $\pi_1 = \pi_2 = 0$

Asymptotic critical values for the t and F distributions are tabulated by Pesaran et al. (2000)[15]. In Appendix 3 we report the t and F critical values for I(1) variables in the case of unrestricted intercept and no trend in the equation.

The second specification of the model also tests the significance of density in the explanation of the dynamics of the upstream industry.

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[15] Although it is more general, we do not use the Johansen method of cointegration because it requires a large number of observations. However, when the number of the variables is no greater than 2, and the independent variable is weakly exogenous, results of the unrestricted ECM are considered robust. In the case of more than two variables the application of the Johansen method to our data produced ambiguous results, probably due to the small number of observations. Therefore, we preferred to use the unrestricted ECM model to study the effects of downstream concentration and density on the upstream concentration, although we cannot check for the number of cointegrating relations.

$$\Delta Eng\_Var_t = \alpha + \beta_0 \Delta Air\_Var_t + \beta_1 \Delta DENS_t + \pi_1 Eng\_Var_{t-1} + \pi_2 Air\_Var_{t-1} + \pi_3 DENS_{t-1} + \varepsilon \qquad (2)$$

These specifications of the models are built on the idea that causality goes from the downstream to the upstream industry. We believe that this hypothesis is realistic in these industries. In fact, while the aircraft industry represents the whole market for the engine industry, influencing directly its dynamics, a reverse causality direction can be assumed to exist in case of radical innovation in components or monopolistic structure of the supplier industry. That is, while one can find interesting examples of innovation in components which determined important changes in the downstream industry (ex. computer and microprocessor, see Malerba et al., 1999; Bresnahan et al., 1999), we believe that this is not the case for the jet and turboprop industries. In fact, in these industries, after the transition to the gas turbine technology, which lead to the disappearance of the commercial piston engine and aircraft industries, no other radical innovation occurred which strongly affected the dynamics of the buyer industry. However, we carry out Granger causality tests to check the statistical significance of the hypothesised direction of causality.

Tables 2-4 show the results of the regressions for the three variables in the turboprop industry.

From the two regressions in table 2 it is clear that there is a positive and significant short run impact of the downstream concentration on the upstream concentration. The F-tests of the restrictions on the coefficients π_1 and π_2 are larger than the critical values in both cases, suggesting cointegration between the three variables. However the coefficient π_2 for the downstream concentration is significant only in the first regression, while in the second regression density explains upstream concentration in the long run.

Results of the regressions in table 3 confirm the existence of a short run relation between downstream and upstream number of firms. The variables are not cointegrated and in the long run density seems to affect negatively the number of firms. The higher the density, the lower are in fact the opportunities available for supplying incumbent firms, already attached to other suppliers. In addition, in a partitioned network density acts as a barrier to entry at a lower level compared to a hierarchical network.

Results in table 4 sharply reveals positive and significant short run and long run relations between the number of new products in the turboprop aircraft and engine industry. The F-statistics are higher than the critical values in both regressions, but in the second the value is smaller as the coefficient for density is not significant.

We carried out a test of Granger causality in the first regression specification for a statistical verification of our hypothesis on the direction of causality. In all three cases it is the downstream variable which drives the upstream and not the reverse.

Table 2. Relation between upstream and downstream concentration - *Turboprop*

Dependent Variable: ΔPE_HERF_t	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	0.111	2.445**	0.099	2.246**
ΔPA_HERF_t	0.599	3.459***	0.400	2.172**
PE_HERF_{t-1}	-0.317	-2.742***	-0.457	-3.653***
PA_HERF_{t-1}	0.213	2.304**	0.039	0.339
$\Delta P\_DENSITY_t$	-	-	0.203	1.729*
$P\_DENSITY_{t-1}$	-	-	0.397	2.432**
Adjusted R-squared	0.32		0.38	
F-statistic	7.76***		6.30***	
F-statistic H_0: $\pi_1=\pi_2=(\pi_3)=0$	9.31		4.70	
serial correlation LM test (F-stat)	0.03		0.21	
n	44		44	

*p<0.10, **p<0.05, ***p<0.01.

Table 3. Relation between upstream and downstream number of firms - *Turboprop*

Dependent Variable: ΔPE_NFIRM_t	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	0.052	0.228	1.369	2.320**
ΔPA_NFIRM_t	0.468	5.248***	0.429	4.841***
PE_NFIRM_{t-1}	-0.128	-1.600	-0.264	-2.761***
PA_NFIRM_{t-1}	0.062	1.401	0.054	1.291
$\Delta P\_DENSITY_t$	-	-	-1.298	-2.010*
$P\_DENSITY_{t-1}$	-	-	-1.798	-2.434**
Adjusted R-squared	0.43		0.55	
F-statistic	11.79***		9.14***	
F-statistic H_0: $\pi_1=\pi_2=(\pi_3)=0$	0.33		2.86	
serial correlation LM test (F-stat)	0.03		0.04	
N	44		44	

*p<0.10, **p<0.05, ***p<0.01.

Table 4. Relation between upstream and downstream number of new products- *Turboprop*

Dependent Variable: ΔPE_NPRO_t	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	0.763	2.957***	1.014	2.474**
ΔPA_NPRO_t	0.461	6.682***	0.449	6.408***
PE_NPRO_{t-1}	-1.145	-7.268***	-1.157	-7.242***
PA_NPRO_{t-1}	0.404	3.609***	0.398	3.536***
$\Delta P\_DENSITY_t$	-	-	-1.440	-1.289
$P\_DENSITY_{t-1}$	-	-	-0.683	-0.865
Adjusted R-squared	0.73		0.73	
F-statistic	39.34***		2.38***	
F-statistic H_0: $\pi_1=\pi_2=(\pi_3)=0$	10.53		19.11	
serial correlation LM test (F-stat)	0.47		0.48	
n	44		44	

*p<0.10, **p<0.05, ***p<0.01.

In the jet results are quite different. The Chow test for the structural stability of the relation between downstream and upstream concentration revealed a structural break in 1978[16]. We carried out the above regressions by including a dummy variable for the intercept and a dummy variable for the

[16] The test for the structural stability has been carried out in all regressions, but only for the concentration in the jet it resulted significant.

coefficient of the downstream concentration (Table 5). Results are very interesting as they show the existence of a short and a long run relation between the two variables but the sign of the relation is different in the two periods. Before 1978, when the density of the network is smaller, and the core of the network is not stable, the sign of the relation is positive. In the second period, the hierarchical network filters the transmissions of the changes of the downstream to the upstream industry. In this case the coefficient for the downstream concentration is negative. In fact larger market shares of the downstream leaders are distributed among suppliers in the core almost equally, leading to a reduction of the upstream concentration. The coefficient for density is significant only in the long run, and this reflects the hierarchisation of the network which is not captured by an aggregate indicator like density. The tests for Granger causality indicate that both directions are significant, suggesting also influence of the upstream on the downstream industry.

The regressions for number of firms and number of new products show that there is no relations between upstream and downstream variables (table 6 and 7). Density seems to affect negatively the number of firms in the short run, suggesting again the role of density as a barrier to entry. In Table 7 the F-values is largely higher than the critical value, but it reflects the higher significance of the lagged dependent variable.

Table 5. Relation between upstream and downstream concentration - *Jet*

Dependent Variable: ΔJE_HERF_t	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	-0.173	-2.353**	-0.324	-3.297***
C2	0.055	0.508	0.087	0.822
ΔJA_HERF_t	1.270	5.872***	1.322	6.340***
ΔJA_HERFT2_t	-0.551	-2.220**	-0.628	-2.608**
JE_HERF_{t-1}	-0.534	-4.808***	-0.545	-4.293***
JA_HERF_{t-1}	1.298	4.930***	1.290	5.011***
JA_HERFT2_{t-1}	-0.569	-2.040**	-0.659	-2.427**
$\Delta J\_DENSITY_t$	-	-	1.015	1.015
$J\_DENSITY_{t-1}$	-	-	0.366	2.197**
Adjusted R-squared	0.53		0.57	
F-statistic	8.11***		7.26***	
F-statistic H_0: $\pi_1=\pi_2=(\pi_3)=0$	9.43		8.65	
serial correlation LM test (F-stat)	1.01		0.42	
n	39		39	

*p<0.10, **p<0.05, ***p<0.01.

Table 6. Relation between upstream and downstream number of firms - *Jet*

Dependent Variable: ΔJE_NFIRM$_t$	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	0.441	1.005	0.701	0.696
ΔJANFIRM$_t$	0.081	0.870	-0.125	-1.317
JENFIRM$_{t-1}$	-0.020	-0.389	-0.027	-0.599
JANFIRM$_{t-1}$	-0.036	-0.626	-0.064	-1.060
ΔJ_DENSITY$_t$	-	-	-4.230	-3.485***
J_DENSITY$_{t-1}$	-	-	-0.077	-0.055
Adjusted R-squared	0.00		0.33	
F-statistic	0.98		4.80***	
F-statistic H_0: π_1=π_2=(π_3)=0	0.74		0.73	
serial correlation LM test (F-stat)	1.98		3.05*	
N	39		39	

*p<0.10, **p<0.05, ***p<0.01.

Table 7. Relation between upstream and downstream number of new products- *Jet*

Dependent Variable: ΔJE_NPRO$_t$	Regression 1		Regression 2	
	Coefficient	t-Statistic	Coefficient	t-Statistic
C	2.407	2.853***	4.841	1.330
ΔJA_NPRO$_t$	0.137	1.635	0.111	1.118
JE_NPRO$_{t-1}$	-0.749	-4.582***	-0.812	-4.576***
JA_NPRO$_{t-1}$	0.025	0.241	0.019	0.164
ΔJ_DENSITY$_t$	-	-	-8.522	-1.219
J_DENSITY$_{t-1}$	-	-	-5.043	-0.625
Adjusted R-squared	0.41		0.40	
F-statistic	9.92***		6.16***	
F-statistic H_0: π_1=π_2=(π_3)=0	28.97		7.38	
serial correlation LM test (F-stat)	0.46		0.37	
N	39		39	

*p<0.10, **p<0.05, ***p<0.01.

Summarising, we observe positive relations between each couple of variables in the turboprop, while in the jet the relation is significant only for the concentration index, with different sign of the coefficients in the two periods, and it is not significant for the number of firms and of new products. How can this difference be explained?

As shown in section 3, the network linking the two industries assumes a sharply different configuration in the two cases. We argue that networks matter, and precisely that the partitioned network directly transmits the effects to the upstream industry, while the hierarchical network filters the effects. How does the network act as a transmission mechanism?

With respect to the *number of firms*, we observed in the turboprop industry that the entry of suppliers always follows the entry of an aircraft manufacturer. In a context characterised by stability of relations, high costs of switching suppliers, and preference towards single sourcing, the opportunities for entry come from the entry of a new unattached buyer and much less frequently from the introduction of a new program. Specialisation by market segments and absence of economies of scale and scope lead to a configuration of the turboprop industry in which engine suppliers operate mainly in just one segment of the market. In this industry context, although turboprop aircraft manufacturers operated mainly in single sourcing, the introduction of a program in a new market segment often required the establishment of a supply relation with a second source. An example is provided by Casa, which was supplied by Garrett in the less than 30-seat segments and by General Electric in the segment 31-50 seats.

In addition, in such a fragmented market the exit of a customer means in the short run the disappearance of the market for the supplier, which is therefore forced to exit the industry. In fact, the interruption of relations due to exit of aircraft manufacturers represents a loss of market shares that cannot be compensated by acquisition of supply relations with existing customers, already attached to competing suppliers in single sourcing. In partitioned networks characterised by the presence of quasi exclusive relations, the higher the density, the lower the probability that a new firm can join the network. The network becomes in fact saturated at a lower level of density.

On the contrary in the jet industry, the entry of jet aircraft manufacturers may produce opportunities for entry of engine suppliers only indirectly through the growth of the market. Entry of suppliers is not fuelled by the entry of new customers or the launch of programs, but by the increasing adoption of multiple sourcing at the aircraft manufacturer and at the program level. Airbus, Boeing and Mc Donnell Douglas operated with three, and in some periods with four or five engine manufacturers. Starting from the B747, other programs such as the A330, the B767 and the B777 have been powered by engines of three different engine manufacturers. The affirmation of multiple sourcing strategies implies that the launch of a new program is an opportunity for more than one engine manufacturer, which compete to gain the launch order or a large share of total orders. However, a number of minor aircraft manufacturers operated in single sourcing, but they did not create opportunities for entry, as their aircraft have been powered by engines of existing suppliers, in most cases by Rolls Royce engines. The coexistence of multiple sourcing within the core and single sourcing at the periphery contributed to the emergence of a cohesive and hierarchical structure of the network. The openness of the network structure, that is the reachability of central nodes of the network, reduces the barriers to entry of new suppliers, which may enter for supplying existing and already attached buyers.

With respect to the level of *concentration*, in the turboprop industry, although the levels of concentration upstream and downstream are very different, their dynamics are highly correlated in the short run. Again the partitioned structure of the network, mirroring an extremely fragmented market structure in which the customer may represent the market of only one supplier, transmits directly the effects of changes in market shares and, therefore, in the level of downstream concentration to the upstream industry. In other words, the growth or the decline of the market share of a customer, or the exit or entry of a customer, cause a growing or declining concentration, respectively. In a fragmented structure, this change impacts on the market share of only one supplier, and induces a change in the level of upstream concentration of the same direction and intensity.

The results of the regressions on total *number of products, and number of new products* in the aircraft and engine industries confirm even more sharply the previous results. In the jet industry there is no relation between number of new products upstream and downstream, while in the turboprop the two variables are cointegrated. In the prop, the technological co-specialisation of engine and aircraft, which is also reflected in the high number of bi-components and of *k*-cores with minimum degree equal to 1, explains the entry of isolated couples of vertically-related firms and products. This means that new engines are realised for specific new aircraft and are very rarely used for other applications. On the other side, a new aircraft is designed to integrate a specific engine. Therefore, the dynamics of the number of products is highly related.

The same pattern of cospecialisation is not observed in the jet.

5. Conclusions and further research

The main message of the paper is that networks matter in the explanation of the evolution of industries. Depending on technology and market factors, networks of vertical relations assume a variety of structural configurations and change over time. Once formed, networks evolve themselves and act as constraints to the evolution of industries, transmitting effects from related industries according to their configuration.

We showed that specific characteristics of the industries, which refer to economies of scope, technological cospecialisation, buyers' sourcing strategies and market segmentation, are reflected in *partitioned* network structures in the turboprop and in *hierarchical* network structures in the jet.

The econometric analysis showed that the structural dynamics of downstream and upstream industries, measured in terms of number of firms, industrial concentration and introduction of new products, are positively related in the turboprop while in the jet there are not significant relations, except for concentration in the first period, when the core is not stabilised and the relation is positive, while in the second period the relation is negative. We propose that partitioned network structures *transmit directly* the changes of downstream to upstream industries, while hierarchical networks *filter* the effects.

The analysis developed in this paper will be applied in different industrial contexts. Further research will aim to study the relations between airline companies and aircraft manufacturers. Two important factors may have affected the sourcing of airlines: the role of commonality across different engines and aircraft, which allows important cost savings for airlines, and the trend toward outsourcing of maintenance activities, which reduces the cost savings of having a single supplier. The analysis of the vertical relations between engine, aircraft and airline industries will offer different cases characterised by different structures of upstream and downstream industries. While in this paper we analysed *small-number buyer and supplier industries*, the analysis of the airline industry will remove this restriction on the downstream side, as the industry is composed of hundreds of companies and is characterised by very turbulent dynamics, also fuelled by the deregulation process that has occurred in the United States and in Europe. Again, the comparison between markets for jet and turboprop aircraft will allow further specifications of market structures and of demand regimes, as the development of air carriers in the markets for turboprop and jet followed differentiated dynamics.

A further development of this work will have as its object of analysis the dynamics of the network of vertical relations between avionics and aircraft manufacturers. In that case we will extend the application of the theory to a *supplier industry* characterised by the presence of a *large number of firms*. The avionics industry is also composed of a number of market segments characterised by different technologies which witnessed strong changes in the last few decades.

The analysis of the network in different industrial contexts will provide cases which will enrich and enlarge the general applicability of the proposed approach.

Appendix 1. Data

Empirical analysis is carried out in the turboprop and jet aircraft-engine industries since their birth to 1997, by using a *proprietary database* built upon several sources of data.

Specifically, we use the *Atlas Aviation* and *Jane's All the World Aircraft* databases, IATA publications, technical press and literature on the history and technological development of the aviation industry[17]. The *Atlas Aviation Database* contains all the transactions occurring from 1948 to 1997 between aircraft manufacturers and airline companies (orders) in the market for large commercial aircraft. The data distinguish the engine technology adopted, jet and turboprop, and for each transaction it is possible to identify the engine model integrated into the aircraft ordered. The jet industry includes all turbojet and turbofan engines, from the first Pratt & Whitney JT3 introduced in 1958. The turboprop includes all turbine propeller engines from the Rolls Royce Conway in the Vickers Viscount in 1948.

The database provides data on more than 85,000 transactions, carried out by 5,900 operators, 27 aircraft companies and 11 engine manufacturers, and involving 102 aircraft models (more than 450 versions) and 260 engine types. For each transaction the database provide three monthly dates: contract, first flight (also indicated as production date), and delivery. We use the first flight as unit of analysis as it is subject to less fluctuation. To reduce discontinuity in the data, monthly dates are transformed into annual dates. Data on three aircraft programs not included in Atlas have been added by using Aerospatiale (1990) data on orders and deliveries.

Transactions include also second-hand transfers between operators. As we are interested in the relations between engine and aircraft manufacturers, we consider only the first introduction of the product and do not consider each subsequent transaction occurring between airline companies. The final number of transactions used in the analysis is 27,000.

[17] Among others, Miller and Sawers, 1968; Phillips, 1971; Klein, 1977; Constant, 1980; Bluestone et al., 1981; Bright, 1981; Mowery and Rosenberg, 1982, 1989; Hayward, 1986, 1994; Vincenti, 1990; World Aerospace Technology, 1993; Norris and Wagner, 1997; Sutton, 1998; U.S. International Trade Commission, 1998.

We integrated the *Atlas* database with data on the number of engines powering each aircraft, by using other sources: *Jane's All the World Aircraft* publications and the technical press (in particular, *Flight International* and *Aviation Week and Space Technology*). Data on seat capacity of aircraft, and information about segmentation by seat are provided by company reports (in particular Boeing, Airbus, Aerospatiale).

Russian aircraft and engine transactions are excluded from this analysis, because of some incompleteness and uncertainty about data in the version of the database used for this research. This is not a problem with respect to the objectives of this thesis, since historically Russian engines have been exclusively integrated into aeroplanes produced in Russia, thus the relational dynamics in the engine industry of the rest of the world are not influenced very much.

Entry is defined as the first date an engine manufacturer supplies an engine to an aircraft manufacturer (indicated by the date of production). A firm experiences exit when it does not supply engines for at least 5 consecutive years. Entry and exit of companies are analysed simply by counting the number of companies in the engine industry and their life cycle. The calculation of rates of entry and exit is not significant given the small number of players.

Data on which concentration measures are computed are based on total sales of commercial aircraft manufacturers over the entire period of observation, expressed in physical quantities (orders). To take into consideration sales of aero-engine firms, aircraft orders are multiplied by the number of engines installed in the model, as described in the technical literature. No consideration is given to the spare units sold in the maintenance and repair market. Market shares are therefore defined in terms of quantities rather than turnover, since there is no such detailed information available at the level of individual aircraft and engine programs.

Appendix 2. List of Variables

Eng_Var	Dependent variable (engine industry)
Air_Var	Independent variable (aircraft industry)
PE_HERF	Herfindahl index - turboprop engine industry
PE_NFIRM	Number of firms - turboprop engine industry
PE_NPRO	Number of new products - turboprop engine industry
PA_HERF	Herfindahl index - turboprop aircraft industry
PA_NFIRM	Number of firms - turboprop aircraft industry
PA_NPRO	Number of new products - turboprop aircraft industry
P_DENSITY	Density of the turboprop network
JE_HERF	Herfindahl index - jet engine industry
JE_NFIRM	Number of firms- jet engine industry
JE_NPRO	Number of new products- jet engine industry
JA_HERF	Herfindahl index - jet aircraft industry
JA_HERFT2	Dummy for Herfindahl index (1978-1997) - jet aircraft industry
JA_NFIRM	Number of firms - jet aircraft industry
JA_NPRO	Number of new products - jet aircraft industry
J_DENSITY	Density of the jet network
C2	Dummy for constant (1978-1997)

Appendix 3. Critical values for F and t

	F		t	
	k=1*	k=2	k=1	k=2
p<0.10	4.78	-4.14	2.91	-3.21
p<0.05	5.73	-4.85	3.22	-3.53
p<0.01	6.68	-6.36	3.82	-4.10

Sources: Pesaran et al. (2000)
*k is the number of independent variables in the regressions. k=1 corresponds to the first regression specification, while k=2 to the second specification.

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