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Network structure and industrial dynamics. The long-term evolution of the aircraft-engine industry

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Network structure and industrial dynamics.
The long-term evolution of the aircraft-engine industry[♣].

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Abstract

This paper proposes a new approach to explain the long-term evolution of a supplier industry. The network of vertical relations between suppliers and buyers is identified as a determinant of the concentration of the supplier industry and of the dynamics of market shares. The vertical structure of the industry is captured by collecting information on *all vertical relations between dyads of firms* and by building matrices of interaction for the aircraft-engine industry from 1953 to 1997. An econometric exercise is used to test some hypotheses about the relation between selected network measures and industrial dynamics.

JEL classification: L13, L19, L22, L62

Key words: industrial dynamics; vertically-related industries; network; industrial concentration; market shares.

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1 Introduction

Industries come to be organised, in the long run, according to dynamics that shape their horizontal structure and vertical configuration. The identification of the properties of these dynamics is the object of much research and explains the recent convergence of interests between structural theories of economic change, evolutionary theories of the firm, and industrial dynamics.

Within this context, the problem of identifying the specific mechanisms that relate the horizontal dynamics of an industry (entry, exit, survival and growth of firms, stability of market shares, firm size distribution) to the vertical dynamics (vertical integration/disintegration or change in the division of labour, industrial dynamics in upstream/downstream sectors) is of much interest. While a certain amount of empirical evidence has been collected on this problem, and some general models have been developed, much work remains to be done.

We propose that the notion of network of relations between suppliers and users captures the vertical organisation of an industry. The originality of this paper lies in the use of economic network time series for the explanation of the long-term dynamics of a supplier industry. We study the relations between engine and aircraft manufacturers in the jet and turboprop markets. The vertical structure of the industries is captured by collecting information on all vertical relations between dyads of firms, by building matrices of interaction for the entire industries during the period 1953-1997, and by computing selected network measures at the industry and at the firm level.

We develop the hypothesis that the structural dynamics of the supplier industry, as represented by the evolution of the level of concentration and the dynamics of market shares, depend on the way vertical relations are created and distributed among actors. We take into account specific factors underlying the creation of linkages between the firms in the two industries and formulate different hypotheses about the sign of the relation between network and industry measures. The question we try to answer is the following: can the distribution of vertical relations in two vertically-related industry affect the level of concentration and the dynamics of firms' market shares of the supplier industry?

An econometric analysis is carried out to test the hypothesis that, depending on the characteristics of the distribution of relations in the networks, relational density has a different impact on the level of concentration of the supplier industry. More precisely, in oligopolistic regimes characterised by asymmetries among actors in relational behaviour, relational density has a positive effect on concentration, while in oligopolistic regimes in which actors follow symmetric relational behaviours, the sign of the relation is negative. As for the firm level, we propose that actor centrality explains market share, but the intensity of the relation depends on characteristics of vertical linkages and on the size distribution of firms in the downstream industry.

The paper is organised as follows. Section 2 offers a brief review of existing contributions on the dynamics of vertically-related industries. It introduces the notion of a network and discusses the potential of network concepts and techniques in industrial economics. Section 3 introduces data, methodology and descriptive statistics of the variables used in the empirical analysis, while section 4 develops the hypotheses of the model. Section 5 presents an econometric analysis and section 6 concludes.

2 Vertical networks and industrial dynamics

The idea that the evolution of the industry may crucially depend on what happens to a vertically-related, downstream industry has been repeatedly proposed in industrial organisation. The earliest formulation of this idea was proposed by J.K. Galbraith with the notion of countervailing power (Galbraith, 1952). It was subsequently placed by Bain (1968) and Scherer (1980) within the structure-conduct-performance paradigm (see also Scherer and Ross, 1990) and recently reprised by von Ungern-Sternberg (1996) and Dobson and Waterson (1997). The main purpose in revisiting the theory of countervailing power is the analysis of the effects of bilateral oligopoly on the price for the buyer industry and for the final consumer. Although appealing, the notion is quite reductive: it is argued that concentration in a downstream industry is followed by parallel processes of concentration in the upstream industry, but no implications are drawn on the specific mechanisms of transmission; other parameters of industrial dynamics such as number of firms and products, entry and exit are simply not considered. Furthermore, there is scarce and contradictory empirical support for the notion (Lustgarten, 1975; LaFrance, 1979; Ravescraft, 1983).

In general, one of the most difficult problems in introducing the vertical dimension in models of industrial dynamics is the definition of the appropriate level of aggregation.

Models in the tradition of structure-conduct-performance in industrial economics and the countervailing power hypothesis represent the two sides of vertical relations in an aggregate way, by defining demand and supply functions of two different industries. At the opposite side, game-theoretic models in industrial organisation derive industry-level equilibrium from the strategic interaction of individual agents, but at the cost of an excess dependence on detailed conditions, which renders them fragile and difficult to generalise (Sutton, 1998).

The transaction cost approach (Williamson, 1985, 1996, 1999) offers an intermediate level of aggregation. Its unit of analysis is not the firm or the industry, but rather the transaction. This is at the same time a more restrictive and a more general level of analysis: on one hand, firms engage in several different types of transactions; on the other hand, transactions have general properties and the minimisation of transaction costs is considered a powerful attractor of the structural evolution of industries. The optimal mode of governance is predicated on properties of transactions that occur in an industry in general, not to properties that are specific to any firm.

The analysis of the coevolution of the structural dynamics of two vertically related industries is also one of the most recent arenas of evolutionary modelling. Recent developments in the modelling of industrial dynamics provide a clear analysis of the relationship between technological regimes, evolution of market demand, and structural evolution of the industry (Dosi et al., 1995, 1997; Malerba and Orsenigo, 1993, 1996; Nelson et al., 1997; Winter et al, 1997). In most cases, the role of market demand is captured by defining the total size of the market (either given or endogenously changing), by positing a demand function at the level of the firm defined in the space of product attributes, and by assuming *ad hoc* mechanisms such as switching costs, source loyalty, and the like.

Recently, in different industries, patterns of vertical integration and disintegration, and division of labour have been observed as relevant engines of changes in industry structures. In the chemical industry the emergence of specialised engineering firms represents an example of the economies of specialisation and division of labour at the industry level, which enormously affected the evolution of the industry structure, through entry of new firms and intensification of competition (Arora and Gambardella, 1998). In the computer industry (Malerba et al., 1998; Bresnahan and Malerba, 1999; Bresnahan and Greenstein, 1999) and in the semiconductor industry (Langlois and Steinmueller, 1999) the emergence of standards and platforms stimulated entry and growth of specialised suppliers of components. In these industries, the changing patterns of vertical integration/disintegration strongly influenced the dynamics of competition.

Our contribution aims to capture an aggregate level of analysis (two vertically-related industries) while preserving information at the micro-level of the individual transaction between buyer and supplier. For this purpose, we introduce network concepts and measures to represent the vertical structure of the industry. The basic unit of analysis is still the single transaction, but it is not isolated from all the other transactions occurring 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”. This idea was also developed by Granovetter (1985), who maintained that dyads of actors, which are not considered as part of a system of relations, still represent an atomistic unit of analysis.

‘Network’ is a concept that has been used in many disciplines, including economics, sociology, and organisational theory, for analysing different structures of interactions among agents (individuals, firms, groups of actors, technical artefacts). In sociologically-oriented approaches to organisational behaviour, analysing both horizontal and vertical relations, the market network has been proposed as a social structure (Burt, 1992; Swedberg, 1994) or as an intermediate form of organisation between market and hierarchies (Powell, 1990). Other authors analysed the *industry network* as composed of different interrelated groups of actors (firms, suppliers, customers, other institutions) and of technological systems (Hakansson and Johanson, 1994; Lundgren, 1995; Rosenkopf and Tushman, 1998). In an economic perspective, network refers to the structure of interactions among agents and represents a level of analysis which incorporates, in addition to the behaviour of agents, the effects of externalities and highlights the role of cooperation, coordination and competition in economic change (Antonelli, 1992; Cohendet et al., 1998). In the economic analysis of industries, network concepts and techniques are increasingly used in the area of inter-firm *horizontal* agreements (joint ventures, licensing, technological alliances, consortia and the like) (Powell, 1996; Orsenigo et al., 1998, 2000).

Our approach to networks differs from many studies of economic networks as it addresses *vertical* instead of horizontal relations between individual actors belonging to two different sets, and it uses *network time series* for the analysis of the evolution of industries.

The notion of network used in this work specifically refers to the vertical relations between firms in a buyer and a supplier industry at different points in time. The single relation represents a supply transaction, or the sum of supply transactions, occurring in a specified period of time between a supplier and a buyer. Specific characteristics of transactions, firms and industries, as extensively described by existing theories, influence the emergence of structures and dynamics of networks over time. Factors featuring vertical relations such as presence of asset specificity, frequency of relations, or pattern of sourcing, are carefully reflected in different network measures at the transaction level, at the firm level (buyer and supplier), and at the overall network level.

The relationship between the dynamics of vertical relations and industrial dynamics can be studied through the analysis of the relationship between industry variables, i.e. level of concentration, dynamics of market shares, entry and exit, and network time series (for an initial suggestion in this direction see Orsenigo et al., 1998, 2000).

In this work, network measures are used to operationalise variables that are introduced in models of industrial dynamics. We hypothesise that the structural dynamics of the supplier industry depend on the way vertical relations are created and distributed among actors. We take into account specific factors underlying the creation of linkages between the firms in the two industries and formulate different hypotheses about the sign of the relation between network and industry measures. In this way, we propose a rigorous methodology of general applicability for the analysis of different industry contexts.

More precisely, we analyse oligopolistic markets and advance the hypotheses that in oligopolistic industrial regimes characterised by asymmetries among actorsin relational behaviour, relational density has a positive effect on concentration of the supplier industry, while in oligopolistic regimes in which actors follow symmetric behaviours, the sign of the relation is negative. As for the actor level, we propose that actor centrality explains market share, but the intensity of the relation depends on its characteristics (e.g. size), and on the size distribution of firms in the downstream industry.

Why is this question interesting for a theory of industrial dynamics?

The answer can be formulated as follows: the factors that influence industrial dynamics in the long run are the same that influence the *sign* of the relationship between network measures and concentration. By investigating the sign of this relation we have immediate access to a set of variables that shape the structure of the industry over time. Our objective is to test the potential of network time series as a conceptual and quantitative methodological tool for explaining the supplier industry structure and dynamics.

This will be undertaken in the next two sections: having defined the measures, we develop hypotheses about the relation between network and industry measures and test them using econometric models.

In sum, with respect to the existing literature on industrial dynamics we offer the following contribution: we take explicitly into account time series of *vertical networks* for explaining industrial dynamics and provide a methodological contribution to study empirically vertically related industries.

3 Industry and network variables

3.1 Data

Empirical analysis is carried out using the Atlas Aviation database, which contains all transactions occurring in the period 1953-1997 between aircraft manufacturers and airline companies (in terms of orders) in the market for large commercial aircraft. The analysis is carried out in two different segments of the commercial aircraft industry: jet and turboprop engines for regional and commercial aircraft.

The data are distinguished by the engine technology adopted (jet or turboprop). For each transaction we can identify the engine integrated into the aircraft ordered. The jet industry includes all turbojet and turbofan engines, since the first Pratt & Whitney JT3 introduced in 1958. The turboprop includes all turbine propeller engines since the Rolls Royce Conway powering the Vickers Viscount in 1953. The database provides data on more than 85.000 transactions, carried out by 27 aircraft companies and 11 engine manufacturers, and involving 102 aircraft models (more than 450 versions) and 260 engine types[1].

We supplemented the Atlas database with data on the number of engines powering each aircraft, from two other sources: *Jane's All the World Aircraft* publications and the technical press (in particular, *Flight International* and *Aviation Week and Space Technology*).

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[1] Russian aircraft and engines transactions are excluded from this analysis because of 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 paper, since historically Russian engines have been exclusively integrated in airplanes produced in Russia, so that the relational dynamics in the engine industry of the rest of the world is not influenced very much.

3.2 Definition of variables

Industry measures

We analyse the level of industrial concentration and the dynamics of market shares of the supplier industry, namely the aero-engine industry. We compute two concentration measures: the CRK and Herfindahl indexes, which are reported in Table 1[2].

Table 1. Network and industry measures

CONCENTRATION MEASURES	
CRK	$CRK = \sum_{i=1}^{K} S_i$ S_i = market share of the company *i*
Herfindahl Index	$HERF = \sum_{i=1}^{E} S_i^2$ $i = 1,2,....,E$ engine manufacturers
NETWORK MEASURES	
Actor Centrality Degree	$ACD_i = \sum_{j=1}^{A} r_{ij}$ r_{ij} = relation between the companies *i* and *j (binary variable)* $i = 1,2,....,E$ engine manufacturers $j = 1,2,....,A$ aircraft manufacturers
Actor Centrality Degree Normalised	$ACDN = \frac{ACD_i}{\sum_{i}^{E} ACD_i}$
Relational Density	$DENSITY = \frac{\sum_{i}^{E} ACD_i}{A * E}$
Group Centralisation	$GC = \frac{\sum_{i=1}^{E} (ACD^{MAX} - ACD_i)}{\sum_{i=1}^{E} (ACD^{*} - ACD_i)} = \frac{\sum_{i=1}^{E} (ACD^{MAX} - ACD_i)}{(A-1)(E-1)}$ ACD^{MAX} = maximum degree ACD^{*} = possible maximum value of degree (theoretical)

Network measures

Network indicators are drawn from social network analysis contributions and adapted for the analysis of vertically related industries (Wassermann and Faust, 1994; Scott, 1991). A network is composed of a set of vertices linked by edges. We study bipartite graphs, in which edges connect actors belonging to different sets and there are no ties within each set (Borgatti and Everett, 1997; Asratian et al., 1999).

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[2] Concentration measures are computed by using data on the orders of commercial engine manufacturers over the entire period of observation, expressed in physical quantities, which are obtained by multiplying aircraft orders 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 on quantities rather than on turnover, since there is no such detailed information available at the level of individual aircraft and engine programmes.

In the industry under analysis, the connections 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 A, whose cells represent the binary variable r “a relation exists / does not exist”. Data about the number of engines exchanged are indicated in a matrix B, whose cells contain zero if the matrix A exhibits zero in the same position and the quantity exchanged if the matrix exhibits one in that position.

We use dichotomous ties (matrix A), instead of valued ties (matrix B), to compute different network indicators[3].

In this work we analyse centrality indexes at actor and group level, which are reported in Table 1.

At the single-actor level we compute measures of *centrality degree*. The degree of an actor is defined as the number of edges incident with that vertex. The total number of edges depends on the network size, that is, on the total number of actors. A more informative index is obtained by normalising the degree, dividing the degree by the total number of connections occurring in the network. This index seizes on the comparison of the relational intensity among the actors, by measuring the share of total relations in which each actor is involved.

At the group level we calculate a *measure of relational density* and a *centralisation index*.

The *density* is 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. It provides information about the group relational intensity and the cohesion of a graph, but does not include information about the variability among actor degrees.

In vertically-related industries density measures the relational intensity among customers and suppliers in the network. A change in density essentially depends on the relational activity of suppliers and on the sourcing strategies of customers. Specifically, density *increases* because of *new relations by incumbents, exit of firms* with a number of relations below the average, or entry of firms with a number of relations above the average. Density decreases because of *interruption of relations by incumbents,* exit of firms with a number of relations above the average, and *entry of firms* with a number of relations below the average. As entry and exit are more likely to occur with a small number of relations, more generally density increases because of increasing relational intensity and decreases because of entry.

We also identify the existence of *cohesive subgroups*, which are subsets of actors among whom there are relatively intense ties. In this analysis the subgroup is composed of all actors having a minimum of 2 relations for at least 5 consecutive years during the period under analysis. Actors who correspond to these criteria (nodal degree and stability of the relation) are selected as members of the core during the entire industry life. In this way we identify a *core* and a *periphery* of the network. The core is composed of the portion of the network whose members have ties to many others within the subgroup. By contrast, the periphery is composed of actors with only one relation, or with two or more unstable relations. We calculate the relational density at the core level in order to highlight relational dynamics within the core and to identify effects of structural differentiation and hierarchical organisation of the network.

The second group-level measure is the *centralisation index*, which measures the extent to which a particular network has a highly central actor around whom more peripheral actors collect (Borgatti and Everett, 1997). The index has the property that the larger it is, the more likely it is that a single actor is central, with the remaining actors considerably less central. It measures how variable or heterogeneous the actor centralities are, providing a measure of inequality and a rough approximation of variability of actors' values (Wassermann and Faust, 1994). We use a modification of the standard Freeman degree centralisation index (Freeman, 1979). The index is obtained in two steps. In the first, we sum the differences between the

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[3] Although we have data on quantities exchanged between each pair of actors, we still use the matrix A as an independent object for the following reasons. First, the information contained in A matrices is more parsimonious and is likely to be available in most markets. Of course, the matrix A can be derived from B. But it may be also available *without* knowing B. In this sense, it is more general and requires less information. In many cases, one has only time series data on market shares and on the existence of relations between buyer-supplier pairs (i.e. one knows only the marginal row of matrix B and the structure of matrix A, but not the individual cells of B). Second, valued relations do not allow differentiating the level of actor centrality: an actor can seem more central than another even if it is linked to a lower number of actors because the quantities associated with the relations are very large. Furthermore, it would be impossible to disentangle the effects on concentration of, respectively, the relational activity of individual firms and the dynamics of quantities. Finally, the matrix containing only data on the existence of relations is itself highly informative for those industries in which market relations are considered

degree of the most central actor and the degree of all the others. In the second we normalise by the maximum possible sum of differences, that is the value obtained in a star graph of the same size[4].

3.3 Descriptive statistics

Let us observe the variables under analysis (see summary statistics in Appendix 2) and then propose our hypothesis.

The evolution of the level of industrial concentration is shown in Figure 1 while the dynamics of market share underlying the process of concentration are shown in Figure 2. While the turboprop industry shows a slightly oscillating, but approximately stable on average, level of concentration, the jet industry clearly shows a decreasing trend. Both indexes confirm these patterns in the two industries.

The decreasing pattern of the Herfindahl index in the jet industry shows that the oligopoly becomes shared among a few major players after the entry of new actors. In turboprops the CR2 index stays high, implying that the market continues to be concentrated around two actors even after new firms enter the industry. However, the industry was marked by the steady reduction of market share of the former leader, which exits from the market, and its substitution by a new leader. The market is always characterised by the presence of a strong leader, and by a few companies with rather unstable market share dynamics.

The description of the evolution of the two industries highlights some interesting questions: First, in both industries the leader was not able to maintain its dominance in the market, despite the industry exhibiting some of the Schumpeterian and Chandlerian conditions for persistence of incumbents. Second, the jet industry experienced a reduction of the level of concentration, although theories would predict a growth in concentration.

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as long-term (strategic) investments. The very existence of a relation, no matter how important it is in terms of quantities, is an indicator of an investment decision.

[4] The star graph occurs when there is an actor *n* relating to all the others, and the remaining *n-1* actors relate only with the central actor. In this situation the index reaches its maximum value of 1. In the Freeman index the denominator is given by $(n-1)*(n-2)$. In the case of two-mode datasets we propose to normalise by dividing by $(n-1)*(m-1)$, which corresponds to the value of a maximally centralised bipartite graph.

Figure 1. Level of industrial concentration

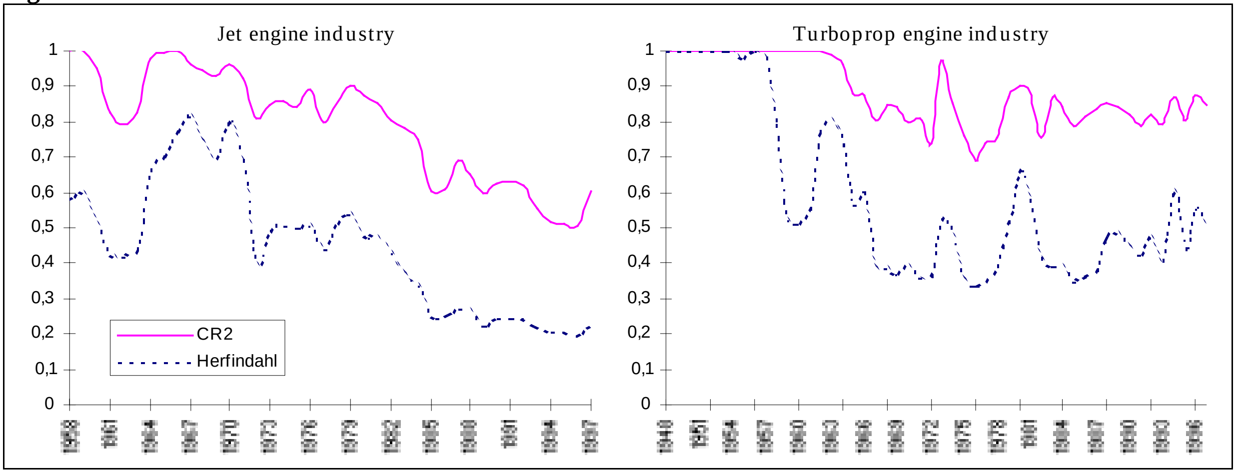
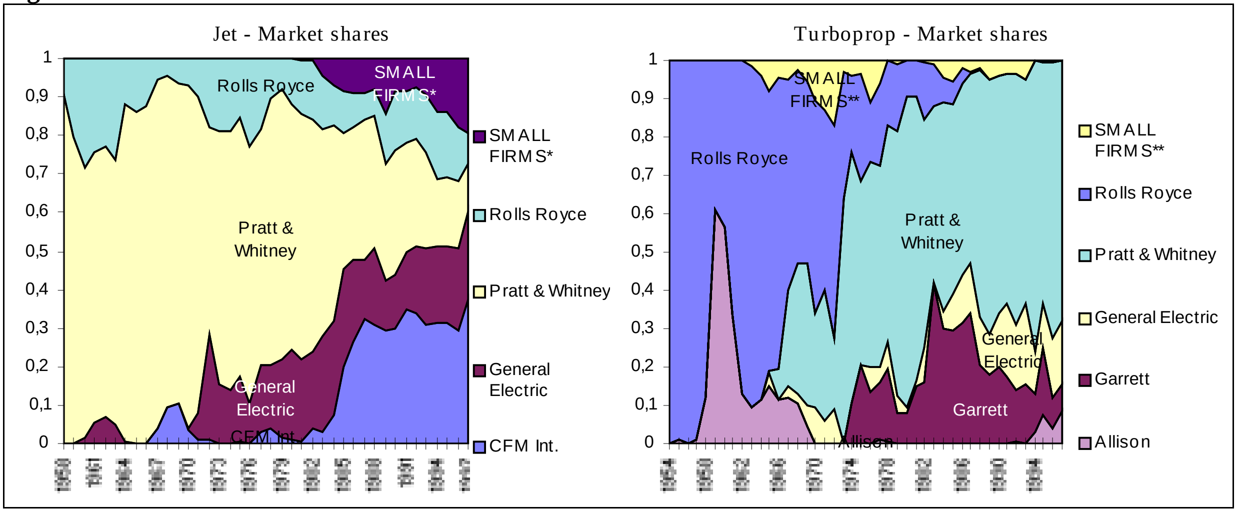


Figure 2. Market shares



*In the jet industry the category SMALL COMPANIES includes: Allison, International Aeroengines and Textron.
**In the turboprop industry the category SMALL COMPANIES includes: Dongan, Lycoming, Turbomeca and Walter.

With respect to the network level, figures 3 and 4 depict the structure of the networks of vertical relations in 1963-67 and in 1993-97 in the turboprop and jet industry[5]. At first glance, by looking at graph cohesion we can observe that the jet industry is characterised by a higher relational intensity than the turboprop. It is also clearly visible that in the turboprop industry the network structure reflects the replacement of the market leader in terms of relations.

Numerical representation of networks (relational density and group centralisation index) are shown in Figure 5. The turboprop industry is characterised by a lower relational density, related to the existence of stable (in many cases one-to-one) relations between aircraft and engine manufacturers, except for the leaders, which display a large number of relations. The turbulence in the group centralisation measure is explained by the turnover of the relational leader in the market. Rolls Royce was the first mover in the market, and it built new relations during the early decades. During the 1960s large companies such as Pratt & Whitney and General Electric entered the turboprop market, by supplying more and more users. This is also made clear in Figure 6, which exhibits the dynamics of actor centrality. Changes in the most central actor are reflected in the dynamics of the centralisation index.

In the jet industry, the value of the density depends on the more pronounced level of cohesion and connection. In the jet network a core emerges, is subject to destabilisation and then expands during the last two decades. The core becomes in fact more dense, as entrants do not integrate well into the network. As is also visible in Figure 3, large engine manufacturers supply all major aircraft producers[6]. The turbulent dynamics of the centralisation index depends on the presence of more than one central actor over time, that is, on the turnover of the central actor. As the pattern of entry and exit is stable, *the dynamics of the network reveals an intense competition among actors in order to gain a central position in the relations with the buyers.*

We show elsewhere that the differences in the network structures 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 (Bonaccorsi and Giuri, 2001).[7]

The question we will address in the following sections is: can time series data about network relationships explain the evolution of industrial concentration and the dynamics of market shares?

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[5] The list of companies is reported in Appendix 1.

[6] In turn, large aircraft manufacturers progressively adopted a strategy of dual, then of multiple sourcing. This strategy allows maintaining competition among engine producers, reducing the dependence on capacity decisions of engine companies in cases of demand growth and satisfying the pressures of airline companies to choose the engine to be incorporated into the aircraft.

[7] The differences between jet and prop with respect to these structural factors have been studied in related papers presenting a detailed case history of the two industries (Bonaccorsi and Giuri, 2000a, 2000b).

Figure 3. Network structure in turbojet sector

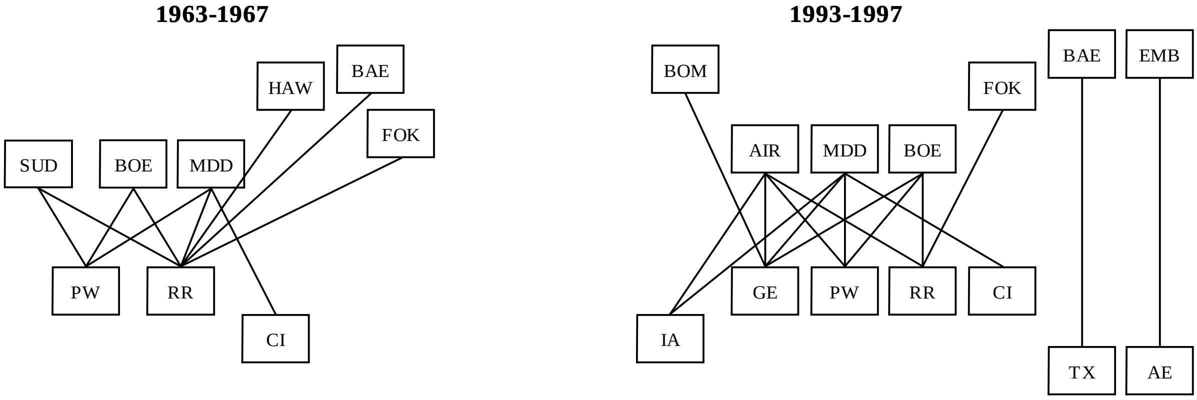

1963-1967 **1993-1997**

Figure 4. Network structure in turboprop sector

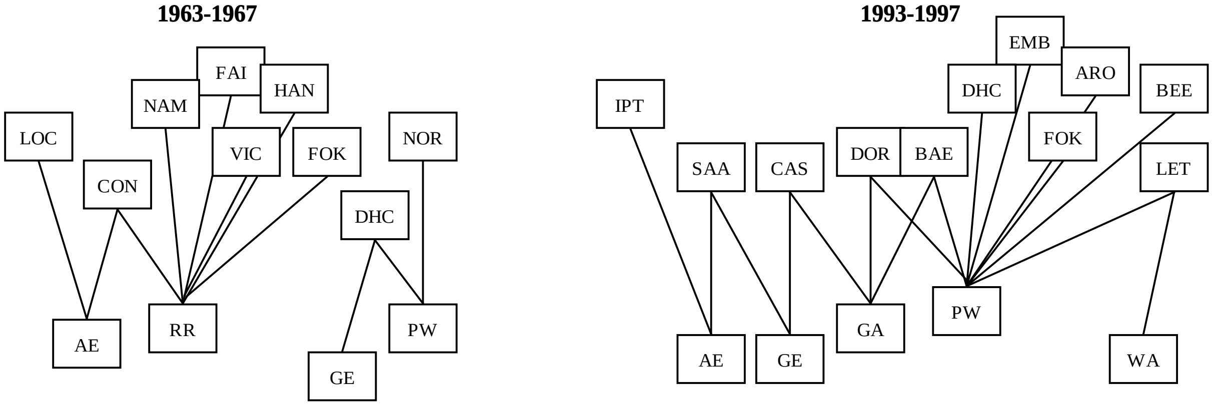

1963-1967 **1993-1997**

Figure 5. Group network measures

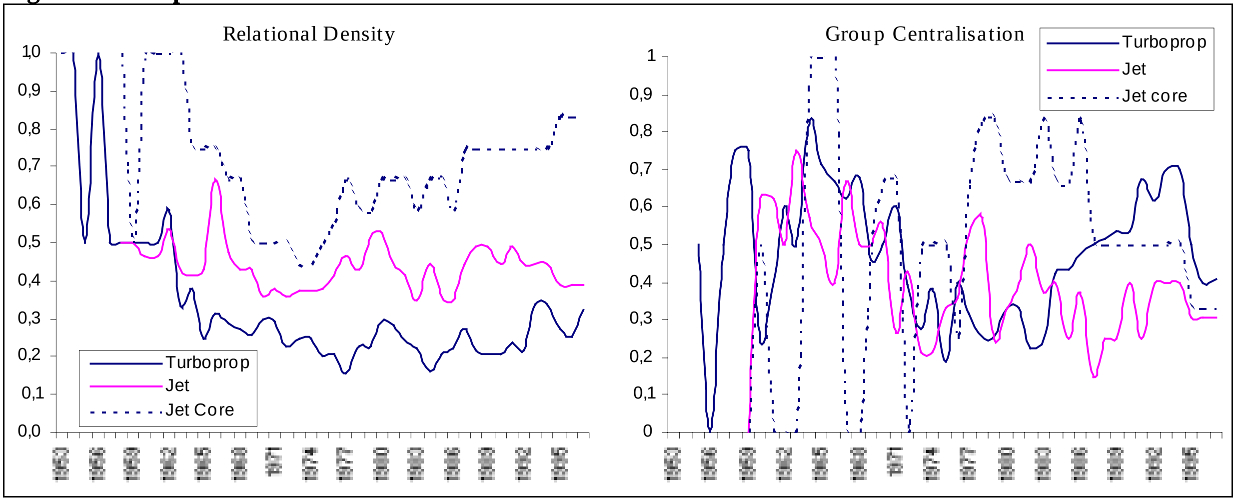
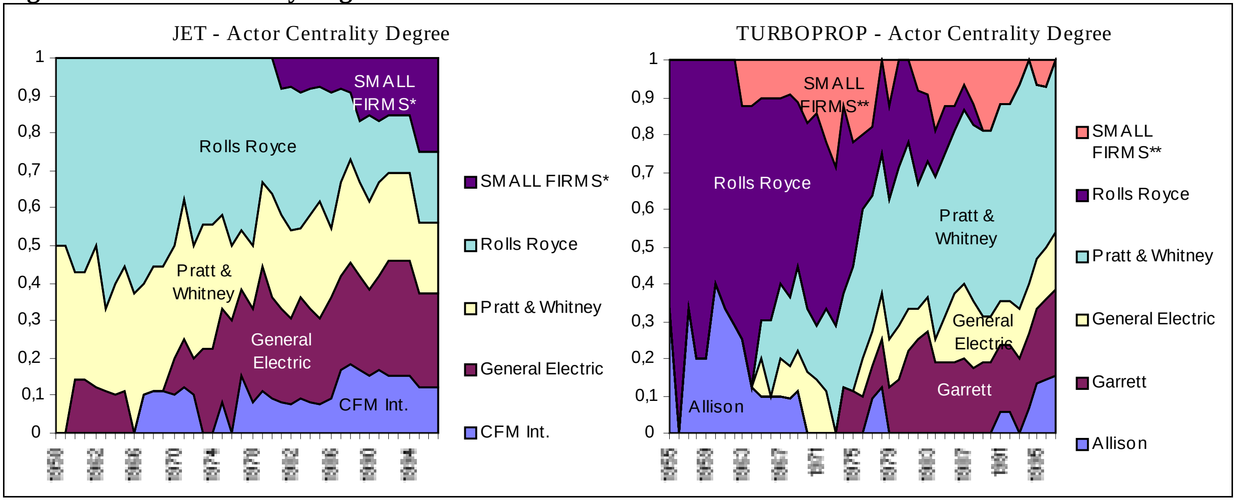


Figure 6. Actor Centrality Degree



*In the jet industry the category SMALL COMPANIES includes: Allison, International Aeroengines and Textron.
** In the turboprop industry the category SMALL COMPANIES includes: Dongan, Lycoming, Turbomeca and Walter.

4 Development of hypotheses

4.1 Group level

We develop the hypothesis that the way relations are distributed influences the dynamics of industrial concentration.

In abstract terms, the relationship between network density and industry concentration is not obvious. Suppose we have a given level of network density, calculated on the interaction matrix A, whose cells represent the binary variable “a relation exists / does not exist”. To this matrix, a matrix B is associated, whose cells contain zero if the matrix A exhibits zero in the same position, and the quantity exchanged if the matrix exhibits one in that position.

Ex. matrix A

	E1	E2	E3	
A1	1	1	0	*2*
A2	0	1	0	*1*
A3	0	0	1	*1*
	1	*2*	*1*	*4*

Ex. matrix B

	E1	E2	E3	
A1	30	30	0	*60*
A2	0	20	0	*20*
A3	0	0	20	*20*
	30	*50*	*20*	*100*

With any given matrix A, an infinite number of matrices (B_1, B_2 ... B_n) can be associated, depending on the distribution of quantities exchanged across the cells (all the matrices B_i share the common feature of constant sum of values). The sum of cells in each column represents the total sales of each supplier; market shares and the concentration index can be calculated on the basis of the marginal row. Therefore, an infinite number of concentration indexes are associated with any matrix A (i.e., a given level of network density).

In dynamic terms, a change in network density (e.g., a change from A to A'), even keeping constant the sum of values of B_i, may produce any kind of effect on concentration indexes. We can conclude that the relation between density and concentration is indeterminate, in both static and dynamic terms. The same conclusion holds if we let the number of actors (i.e., the number of columns and rows in A) change over time.

Let us take the second group relational measure - group centralisation. It is calculated from the same matrix A. Again, the number of matrices B_i associated with A, keeping the group centralisation index constant, is infinite. The relation between group centralisation and concentration is again indeterminate.

The key point is that to make the relation between network measures and concentration determinate *one has to place restrictions on the admissible distribution of quantities* across the non-zero cells in the B_i matrices.

An exploratory analysis of the mathematical formulation of this problem shows that a systematic relation between density and concentration may well exist, but only under some well defined restrictions, for example on the form of A, the distribution of differential quantities in B, the existence of a lower bound on individual differential quantities. This means that some substantive assumptions must be made regarding the process underlying the creation of linkages in the A matrix and the distribution of quantities in the B_i matrices.

Let us frame the problem in abstract terms. Assume the initial configuration of the market is represented by a diagonal matrix - each supplier sells to only one customer. Alternatively, all suppliers have approximately the same number of relations. Suppose further that any new relation can originate from any of the existing suppliers (i.e., in matrix A any cell 0 may switch to 1 with approximately the same probability).

Now, assume with no loss of generality that the total size of the market remains unchanged (i.e., all matrices B' have the same sum of cells as matrices B). This implies that the quantity gained by the newly created relation must be compensated by "losses" in other existing relations. Suppose that the law of distribution of losses to other relations is either uniform or normal. Under these conditions, it can be shown mathematically that the relation between density and concentration may assume a negative or positive sign.

Interestingly, the relation is negative if the perturbation induced by the new relation (i.e., the quantity lost by other relations) is small with respect to market size or average quantity exchanged. These conditions approximate the dynamics of a competitive market, in which relational activity of supplier firms is not sufficiently strong to induce concentration in market shares. On the contrary, the higher the dynamism in opening new relations, the lower the resulting concentration.

Having defined the baseline case, there are at least three conditions under which the relation between density and concentration becomes positive.

First, if the *perturbation is sufficiently large*, then the sign may be positive even if the initial matrix is diagonal and the law of distribution of losses is uniform or normal. This means that stochastic perturbations in the network may induce concentration in the market, provided all new relations imply sufficiently large quantities. This is clearly a case in which indivisibilities are operating. In some industries a new relation requires high transaction-specific investments due to dedicated technologies and human capital, experimentation and testing procedures and facilities. In other cases the discontinuous nature of demand creates a threshold in the market and a relational barrier to entry. This often implies a high value of the quantity associated with the new relation.

Second, there may be *asymmetries in the distribution of new relations*. Irrespective of the initial configuration of the matrix A, the probability of creating new links can be uniform for all actors, normally distributed or, on the contrary, asymmetric. In the latter case we may assume that the higher the number of relations enjoyed by an actor, the higher its probability of creating new links. If this is the case, the increase in density of relations may be associated with an increase in concentration. "Success breeds success" phenomena, reputation effects, source loyalty on the part of the customers and effects of learning from different users may explain why more central companies have a higher probability of creating new links.

Third, asymmetry may be assumed in the *distributions of losses to existing relations*. Irrespective of the distribution of new relations, there can be different rules for distribution of losses. Asymmetric rules favour companies with higher market shares, or with a higher centrality in the case of non-diagonal matrices. In other words, the share of loss is inversely proportional to the number of existing relations or to the market share.

Taking into account these factors, it is possible to formulate different hypotheses about the sign of the relation between density and concentration. In economic terms, this corresponds to the specification of classes of restrictions on the way in which linkages are created in the market. The hypothesis is that in different configurations of networks, relational density has a different impact on the level of concentration. More precisely, in oligopolistic regimes characterised by asymmetric relational behaviours of actors, relational density has a positive effect on concentration, while in oligopolistic regimes characterised by actors which follow symmetric relational behaviours, the sign of the relation between density and concentration is negative.

In the industries under analysis, there are good reasons to expect a *positive* relation between change in density and in concentration. In fact, the creation of linkages requires an up-front fixed investment cost; interactions tend to be sticky, leading to stability in the density of the network, and stickiness is greatly favoured by the idiosyncratic, relation-specific type of technological learning. Changes in density are mainly produced by new linkages, which, however, are mainly realised by incumbent firms. This also produces heavy restrictions on the distribution of quantities across firms. Given a lower bound on quantities exchanged within each new buyer-supplier linkage, the increase in density leads to an increase in concentration. Symmetrically, density decreases because new entrants enter with a number of relations below the average. In this case, given the assumptions above, concentration is likely to decrease, again leading to a positive relation.

For the same reasons, we expect that group centralisation positively affects concentration, as relations tend to concentrate around one or a few actors.

4.2 Actor level

With respect to the relation between actor centrality and market shares, a number of studies have already argued that firms enjoying large market shares have an higher probability of increasing the number of customers. We test this hypothesis and we expect that in the long run the cumulative effect of large market shares influences the firms’ relational capacity, via the exploitation of buyers’ switching costs. In other words, we expect that effects of reputation and market power gained by companies create inertia and stability of relations with their users, which positively influence the capability of the company to increase relational intensity.

We also propose that actor centrality contributes to explain market shares. As for the group level, without some assumptions related to the quantities associated to the relations, the impact of changes of actor centrality on market shares is indeterminate. In the industries under analysis we identify two plausible restrictions. First, actors that increase their centrality are likely to be incumbent firms; given a lower bound on quantities, the addition of new relations also means that total quantities increase with respect to competitors and, therefore, market shares increase. Thus, we expect a positive relation between changes in centrality and dynamics of market shares.

The second restriction derives from the size distribution of the downstream industry. If the downstream industry has a uniform size distribution, then any increase in actor centrality leads to increase in market share. On the contrary, if the size distribution is highly skewed, then the effect of increase in centrality on market share depends on whether new linkages are activated with large or small customers.

The jet and turboprop industries are both characterised by large quantities associated to the relations, while concentration in the downstream industry is very different. While the jet aircraft industry is strongly concentrated, and characterised by a skewed firm size distribution, market shares of turboprop aircraft manufacturers are very similar, leading to a low level of concentration. Therefore we expect for both industries a positive effect of actor centrality and market shares, with a stronger intensity in the turboprop industry.

5 Econometric analysis

In this section we test the potential of network measures to explain the structure and dynamics of the supplier industry. We carry out some regression analyses for the entire period under observation to test the existence of a relation between measures describing the dynamics of industry and the network of vertical relations, at both group and actor level.

5.1 Specification

At the industry level we test the hypothesis that group relational measures are significantly and positively related to industry concentration. We build two regression models in which the dependent variable is the Herfindahl index of concentration (*HERF*), while the independent variables (*NET*) are, in turn, relational density (*DENSITY*) and group centralisation (*GC*) (see Appendix 2 for the list of variables). These regressions are carried out for the turboprop and the jet markets.

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:

$$\Delta HERF_t = \alpha + \beta_0 \Delta NET_t + \pi_1 HERF_{t-1} + \pi_2 NET_{t-1} + \varepsilon_t$$

This equation is a reparametrisation of an ARDL(1) process (1st order Auto Regressive Distributed Lags 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 hypotheses:

H_0: π_1=0

H_1: π_1 =π_2 =0

Asymptotic critical values for the t and F distributions are tabulated by Pesaran et al. (2000)[8]. 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.

We are mainly interested in the significance of the model, indicated by the F-value, and in the significance and sign of the coefficients β_0 and π_2. Since concentration does not depend only on relational measures, we do not expect a high value of R^2. In fact, R^2 is typically low in these regressions, leaving room for other explanatory variables.

At the actor level we test the existence of a positive relation between actor centrality and market shares. We test both directions of causality and carry out a test of Granger-causality. If the two variables are cointegrated, both directions can be significant. We deal with a combination of time series and cross section data, which poses a problem of correct aggregation of data (Pesaran, 1997). In order to reduce this problem we carry out three

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[8] 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.

regressions using alternative specifications, each characterised by a different level of aggregation of data.

First we group all actors and use panel data (model *a*, eq. 2-3). In this way we implicitly assume the existence of a representative agent and ignore important differences among actors. Second, we introduce dummy variables to discover possible effects at the firm level (model *b*, eq. 4-5); in this case we take into account firms' differences while still considering the existence of commonality in the pattern of relationship between actor centrality and market shares. Third, in order to discover different patterns of relation between actor centrality and market shares, we use a decompositional model in which regressions are carried out separately for each firm, without considering any commonality effect across them (model *c*, eq. 6-7). The equations are reported in Appendix 4[9].

5.2 Estimation and interpretation of results

Tables 2-4 show the results of the regressions for the industry level and reveal some interesting differences between jet and turboprop industries.

The regression for the turboprop industry in table 2 shows that there is a positive and significant short-run and long-run impact of *density on concentration*. The F-tests of the restrictions on the coefficients π_1 and π_2 are larger than the critical values in the turboprop industry, suggesting cointegration between the two variables. R^2s are not very high but this suggests that other variables should enter to explain the dependent variable. The positive sign of the coefficients β_0 and π_2 confirms our hypothesis. New relations are mainly realised by the relational leader, leading to an increase in density and concentration. Symmetrically, density decreases because new entrants enter with a number of relations below the average. Concentration also decreases, again leading to a positive relation.

In the jet industry, results are not significant. In fact, the level of relational density has been influenced by two opposite forces: the increasing number of relations created by a group of large incumbents and the entry of new companies with a few relations (most often only one). Respectively, these forces determined a growth and a reduction of the value of density, and a decrease of the concentration. As we already showed, the jet network has also been characterised by the emergence and expansion of a core of highly connected actors. We carry

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[9] In this analysis we use yearly data on orders. While our database allows us to use data at intra-year level (by tracking the month of first flight of individual airplanes), we believe that the increase in the number of observations is not compensated by the loss of economic significance of data. We are studying the long run evolution of two industries in which the cycle of marketing and purchase decisions is relatively long.

out another regression to study the relation between *density of the core and concentration*. The Chow test for the structural stability of the relation between density of the core and concentration revealed a structural break in 1978, therefore we carried out the regression by including a dummy variable for the slope (Table 3). Results are very interesting as the coefficients for the first period, when the core is small and unstable, are not significant in the long run and weakly significant in the short run, while they are negative and significant in the second period, when the core becomes more and more dense and competition intensifies considerably. This results are in support of our hypothesis of negative relation between density and concentration. This case resembles in fact the dynamics of a more competitive oligopolistic market where new linkages are created with equal probability by all companies and the relational activity - very intense - is not sufficiently strong to induce concentration in market shares. The threshold value of the perturbation necessary to observe a positive relation should be very high, given the lower bound of the quantities that characterises this industry.

Interestingly, we observe an oligopolistic industry characterised by a relatively low level of concentration because of the presence of intense competition among four large players, none of which was able to drive competitors out of the industry (as it happened in the aircraft industry). The prevalence of the effects of large incumbents is clearly visible in the negative sign of the coefficient.

The relationship between *group centralisation and concentration* is found to be significant only in the jet industry, and the signs of the coefficients confirm our expectations[10] (Table 4). The information embodied in the group centralisation index places more emphasis on the role of the more central actors. In this case, in the jet industry both forces identified above induce a decrease of the index. Thus, the relationship between group centralisation and concentration is found to be positive.

In the turboprop industry the results are not significant. The group centralisation index shows a very high variation due to the change of the relational leader (first a decreasing and then an increasing trend), whereas the level of concentration varies at slower rates. Even if the leader changed, the industry structure did not change with the same intensity because it remained shaped around a leader in the market. During the phase of leader change the level of concentration decreased, but the overall structure was not destabilised, because no other company except P&W gained consistent market shares.

Table 2. Relationship between concentration and density

Dependent Variable: Δ*HERF*	Δ*J_HERF*		Δ*P_HERF*	
	Coeff.	T	Coeff.	T
C	-0.08	-0.72	0.12	3.19***
$\Delta DENSITY_t$	0.19	0.86	0.27	2.43***
$HERF_{t-1}$	-0.08	-1.22	-0.56	-4.84***
$DENSITY_{t-1}$	0.24	0.99	0.50	3.95***
Adj. R-squared	-0.06		0.33	
F-stat.	0.77		8.16***	
F-stat. H_0: $\pi_1=\pi_2=0$	1.06		11.74	
serial correlation LM test (F-stat)	0.22		1.55	
N	39		44	

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

Table 3. Relationship between concentration and density of the core

Dependent Variable: ΔJ*_HERF*		
	Coeff.	t
C	0.29	1.97*
ΔDEN_COREt	-0.17	-1.85*
$\Delta\ DEN\_COREt2$	-0.49	-4.29***
$HERF_{t-1}$	-0.29	-2.22**
DEN_CORE_{t-1}	-0.14	-1.36
DEN_CORET2_{t-1}	-0.15	-2.08**
Adj. R-squared	0.38	
F-stat.	5.63***	
F-stat. H_0: $\pi_1=\pi_2=0$	1.71	
serial correlation LM test (F-stat)	3.04	
N	39	

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

Table 4. Relationship between concentration and group centralisation

Dependent Variable: Δ*HERF*	Δ*J_HERF*		Δ*P_HERF*	
	Coeff.	t	Coeff.	t
C	-0.04	-1.01	0.19	2.94***
ΔGCt	0.04	0.40	-0.14	-1.14
$HERF_{t-1}$	-0.16	-2.06**	-0.45	-3.65***
GC_{t-1}	0.26	2.22**	-0.02	0.19
Adj. R-squared	0.10		0.30	
F-stat.	2.39*		5.66***	
F-stat. H_0: $\pi_1=\pi_2=0$	3.08		6.93	
Serial correlation LM test (F-stat)	0.63		0.06	
N	37		34	

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

At the firm level the results of model *a* are significant for both the equations 2 and 3 (Table 5). In the turboprop industry short-run and long-run effects are both significant and of the expected sign, while in the jet industry only the coefficients for the short run effects are significant and R-squared is quite low. The test of Granger causality shows that market shares

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[10] For these regressions, we did not use the observations for the first years of the industry life, when the number of suppliers were one or two, because they create a substantial turbulence in the group centralisation index, depending only on the small number of network vertices. Therefore, for the jet we use observations beginning in 1960, while in the turboprop observations beginning in 1963.

drive actor centrality with a greater intensity than the reverse. In many cases only the coefficient for this direction is significant.

In the model with dummy variables R^2 are higher but t-values for dummies are significant in only a very limited number of cases. In the turboprop industry the signs of the coefficients, even if not significant, are consistent with the hypothesis for almost all variables. In the jet industry the coefficient π_2 is negative, which reflects the asymmetric buyers' size distribution. Having a larger centrality does not imply larger market shares if relations are with small companies which place small orders. Moreover, centrality in a dense core reflects the equalisation of actors' opportunities, with unpredictable effects on market shares[11]. Results are also confirmed by the decompositional model (Table 7). In fact in the jet industry (equation 6), the coefficient β_0 is positive and significant only for Rolls Royce, while the coefficient π_2 is negative and never significant. The dynamics of Pratt & Whitney's market share displays a decreasing trend over time, especially in recent decades, when collaborations enter the industry and General Electric gains a strong market and relational position. We can observe that all central firms in the network have a persistent market share, but competition among major players is very intense, so that instability in market shares is very high.

In model *a*, equation 3, coefficients π_2 are positive and significant for three companies. In fact market leaders gain resources that can be employed to build new relations, and at the same time they increase reputation, which facilitates the creation of relations with new users. The effects of reputation and investments on new relations are visible especially in the long-run.

In the turboprop industry, only for the two leaders (RR and PW) there is a positive and significant effect of actor centrality on market shares. For the other companies, with a low and stable centrality degree, market shares are more unstable, because of the marked dependence on fluctuations of orders of individual downstream users. The reverse equation is significant for a larger number of companies, as also confirmed by the tests of Granger causality. Only for Garrett, the coefficient π_2 is negative, reflecting an increase in market shares paralleled by a reduction of the centrality relatively to the competitors. In this case the size of customers matters.

In sum, the results reveals the existence of differentiated patterns of relationship between centrality and market shares in the turbojet industry compared to the turboprop industry. In the turboprop industry, in fact, the size distribution of buyers is less skewed than in the jet industry, so that any new linkage brings similar quantities of orders. Consequently, changes in centrality translate directly into changes in market shares. In the jet industry the emergence of a dense core of actors with similar positions breaks the positive relation between centrality and market shares, as central firms are all linked to large customers, and the distribution (turbulent) of market shares is not predictable.

Table 5. Relationship between actor centrality and market shares - ***Model a***

	ΔJ_MS		ΔP_MS			ΔJ_ACD		ΔP_ACD	
	Coeff.	t	Coeff.	t		Coeff.	t	Coeff.	t
C	0.02	2.18**	0.00	-0.39	C	0.01	1.57	0.03	3.59***
ΔACD_t	0.16	2.01**	0.34	3.16***	ΔMS_t	0.16	2.01**	0.18	3.16***
MS_{t-1}	-0.05	-2.66***	-0.32	-4.86***	ACD_{t-1}	-0.08	-2.79***	-0.47	-8.35***
ACD_{t-1}	-0.03	-1.03	0.35	3.97***	MS_{t-1}	0.01	0.81	0.32	7.27***
Adj. R-squared	0.08		0.13		Adj. R-squared	0.07		0.30	
F-stat.	5.35***		9.04***		F-stat.	4.55***		2.42***	
F-stat. H_0: $\pi_1=\pi_2=0$	5.08		3.92		F-stat. H_0: $\pi_1=\pi_2=0$	12.51		34.93	
S.E. regr.	0.05		0.09		S.E. regr.	0.05		0.07	
N	151		163		n	151		163	

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[11] The results in the jet industry could also be affected by the presence of collaboration, because General Electric, Pratt & Whitney and Rolls Royce participate in CFM International and International Aeroengines; so by separating relational activities and market shares of these companies from what comes from the collaboration we do not consider the complete story. We tried to verify this problem by splitting the collaborations among their members and retesting the hypothesis at the single firm level. The results did not show much difference and confirmed the same pattern observed in the regressions considering the cooperation as an independent company. Some slight differences are observed at single firm level.

Table 6. Relationship between actor centrality and market shares - *Model b*

	ΔJ_MS			ΔJ_ACD			ΔP_MS			ΔP_ACD	
	Coeff.	t		Coeff.	t		Coeff.	t		Coeff.	t
C	0.03	0.99	C	0.07	3.00	C	0.06	0.88	C	0.12	3.32***
ΔJ_ACD_t (CI)	0.03	0.11	ΔMS_t (CI)	0.02	0.11	ΔACD_t (AE)	0.23	0.79	ΔMS_t (AE)	0.08	0.69
J_MS_{t-1} (CI)	0.06	0.51	ACD_{t-1} (CI)	-0.93	-3.67***	MS_{t-1} (AE)	-0.46	-2.43**	ACD_{t-1} (AE)	-1.05	-6.77***
J_ACD_{t-1} (CI)	-0.25	-0.67	MS_{t-1} (CI)	0.23	2.68***	ACD_{t-1} (AE)	0.16	0.41	MS_{t-1} (AE)	0.45	4.18***
DJ_GE	0.11	1.81*	DJ_GE	0.04	0.81	DP_GA	-0.08	-0.74	DP_GA	-0.07	-1.12
DJ_PW	0.01	0.19	DJ_PW	0.03	0.72	D P_GE	-0.06	-0.74	D P_GE	-0.09	-1.92*
DJ_RR	0.03	0.71	DJ_RR	-0.12	-3.33***	D P_PW	0.05	0.65	D P_PW	-0.07	-1.29
DJ_TX	-0.05	-0.38	DJ_TX	-0.04	-0.33	D P_RR	-0.11	-1.54	D P_RR	-0.04	-0.91
D$\Delta JACD_GE_t$	-0.40	-1.00	DΔJS_GE_t	-0.25	-0.82	D P_TU	-0.14	-0.75	D P_TU	-0.04	-0.40
D$\Delta JACD_PW_t$	0.07	0.21	DΔJS_PW_t	0.03	0.11	D P_WA	-0.07	-0.58	D P_WA	-0.06	-1.15
D$\Delta JACD_RR_t$	0.30	0.99	DΔJS_RR_t	0.69	2.42**	D$\Delta PACD_GA_t$	0.69	0.73	DΔPS_GA_t	0.00	0.02
D$\Delta JACD_TX_t$	0.42	0.24	DΔJS_TX_t	0.06	0.09	D$\Delta PACD_GE_t$	0.29	0.57	DΔPS_GE_t	0.43	1.41
DΔJS_GE_{t-1}	-0.67	-3.00***	D$\Delta JACD_GE_{t-1}$	0.45	1.47	D$\Delta PACD_PW_t$	0.10	0.22	DΔPS_PW_t	0.00	-0.02
DΔJS_PW_{t-1}	-0.03	-0.26	D$\Delta JACD_PW_{t-1}$	0.33	1.18	D$\Delta PACD_RR_t$	0.05	0.15	DΔPS_RR_t	0.13	0.83
DΔJS_RR_{t-1}	-0.44	-2.40**	D$\Delta JACD_RR_{t-1}$	0.86	3.35***	D$\Delta PACD_TU_t$	0.08	0.06	DΔPS_TU_t	0.05	0.09
DΔJS_TX_{t-1}	-0.44	-0.95	D$\Delta JACD_TX_{t-1}$	0.54	0.37	D$\Delta PACD_WA_t$	0.10	0.08	DΔPS_WA_t	0.78	0.56
D$\Delta JACD_GE_{t-1}$	0.17	0.39	DΔJS_GE_{t-1}	-0.15	-0.64	DΔPS_GA_{t-1}	0.14	0.39	D$\Delta PACD_GA_{t-1}$	0.98	2.71***
D$\Delta JACD_PW_{t-1}$	-0.01	-0.03	DΔJS_PW_{t-1}	-0.12	-1.29	DΔPS_GE_{t-1}	0.13	0.31	D$\Delta PACD_GE_{t-1}$	0.55	1.68*
D$\Delta JACD_RR_{t-1}$	0.25	0.65	DΔJS_RR_{t-1}	0.24	1.49	DΔPS_PW_{t-1}	-0.12	-0.51	D$\Delta PACD_PW_{t-1}$	0.90	4.27***
D$\Delta JACD_TX_{t-1}$	0.87	0.52	DΔJS_TX_{t-1}	-0.23	-0.46	DΔPS_RR_{t-1}	0.04	0.18	D$\Delta PACD_RR_{t-1}$	0.31	1.71*
						DΔPS_TU_{t-1}	-0.26	-0.35	D$\Delta PACD_TU_{t-1}$	0.29	0.29
						DΔPS_WA_{t-1}	-0.18	-0.07	D$\Delta PACD_WA_{t-1}$	0.12	0.16
						D$\Delta PACD_GA_{t-1}$	0.30	0.49	DΔPS_GA_{t-1}	-0.60	-2.76***
						D$\Delta PACD_GE_{t-1}$	0.12	0.19	DΔPS_GE_{t-1}	-0.16	-0.58
						D$\Delta PACD_PW_{t-1}$	0.40	0.92	DΔPS_PW_{t-1}	-0.42	-2.73***
						D$\Delta PACD_RR_{t-1}$	0.33	0.77	DΔPS_RR_{t-1}	0.09	0.68
						D$\Delta PACD_TU_{t-1}$	0.86	0.54	DΔPS_TU_{t-1}	-0.23	-0.37
						D$\Delta PACD_WA_{t-1}$	0.24	0.15	DΔPS_WA_{t-1}	-0.70	-0.35
Adj. R-squared	0.16		Adj. R-squared	0.29		Adj. R-squared	0.14		Adj. R-squared	0.39	
F-stat.	2.51**		F-stat.	4.19**		F-stat.	2.01***		F-stat.	4.88***	
S.E. regr.	0.05		S.E. regr.	0.05		S.E. regr.	0.09		S.E. regr.	0.06	
n	151		n	151		n	163			163	

Note: The description of variables is in Appendix 2. The D letters preceding the independent variables indicates the dummies for companies.

Table 7a. Relationship between actor centrality and market shares - *Model c* - JET

	ΔJS_CI		ΔJS_GE		ΔJS_PW		ΔJS_RR		ΔJS_TX	
	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t
C	0.03	1.24	0.14	3.02***	0.04	0.78	0.06	2.76***	-0.02	-0.44
ΔACD_t	0.03	0.14	-0.37	-1.44	0.10	0.41	0.33	3.27***	0.45	0.70
MS_{t-1}	0.06	0.64	-0.61	-3.61***	0.03	0.40	-0.39	-3.38***	-0.38	-2.26**
ACD_{t-1}	-0.25	-0.85	-0.08	-0.39	-0.26	-1.14	-0.01	-0.11	0.62	1.02
Adj. R-squared	-0.05		0.43		0.02		0.31		0.20	
F-stat.	0.57		7.56***		1.20		6.65***		2.26	
F-stat. H_0: $\pi_1=\pi_2=0$	0.36		9.54		0.76		6.18		3.19	
LM test (F-stat)	1.91		1.17		0.17		6.56**		0.08	
N	30		27		39		39		16	
	$\Delta JACD\_CI$		$\Delta JACD\_GE$		$\Delta JACD\_PW$		$\Delta JACD\_RR$		$\Delta JACD\_TX$	
C	0.07	3.83***	0.11	3.09***	0.09	2.95***	-0.05	-1.45	0.03	1.41
ΔMS_t	0.02	0.14	-0.23	-1.44	0.05	0.41	0.71	3.27***	0.09	0.70
ACD_{t-1}	-0.93	-4.69***	-0.48	-3.76***	-0.60	-4.37***	-0.07	-1.08	-0.39	-1.50
MS_{t-1}	0.23	3.42***	0.08	0.48	0.110	2.45**	0.48	2.71***	0.00	0.01
Adj. R-squared	0.42		0.37		0.33		0.24		-0.03	
F-stat.	7.93***		6.05***		7.38***		4.90***		0.86	
F-stat. H_0: $\pi_1=\pi_2=0$	11.01		7.46		9.53		3.92		1.13	
LM test (F-stat)	0.76		0.18		2.26		11.32***		0.66	
N	30		27		39		39		16	

Table 7b. Relationship between actor centrality and market shares - *Model c* - TURBOPROP

	ΔPS_AE		*ΔPS_GA*		*ΔPS_GE*		*ΔPS_PW*		*ΔPS_RR*		*ΔPS_TU*		*ΔPS_WA*	
	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t	Coeff.	t
C	0.06	0.49	-0.03	-0.36	0.00	-0.07	0.11	1.77	-0.06	-1.24	-0.08	-1.31	-0.01	-0.93
ΔACD_t	0.23	0.44	0.92	1.28	0.52	3.18***	0.33	0.86	0.28	1.39	0.31	0.67	0.33	1.89*
MS_{t-1}	-0.46	-1.35	-0.32	-1.31	-0.33	-2.28	-0.58	-3.85***	-0.42	-2.50**	-0.72	-2.77**	-0.64	-1.80
ACD_{t-1}	0.16	0.23	0.46	1.22	0.27	1.48	0.55	2.51**	0.49	2.19**	1.02	1.82*	0.40	1.91*
Adj. R-squared	-0.02		0.19		0.27		0.31		0.09		0.30		0.51	
F-stat.	0.92		2.77*		4.90***		5.58***		2.14		2.84*		5.23**	
F-stat. H_0: $\pi_1=\pi_2=0$	1.37		1.25		2.59		7.51		3.21		4.16		4.09	
LM test (F-stat)	3.06		0.15		2.80		0.21		2.09		1.97		2.16	
N	14		23		32		32		35		14		13	
	ΔPACD_AE		*ΔPACD_GA*		*ΔPACD_GE*		*ΔPACD_PW*		*ΔPACD_RR*		*ΔPACD_TU*		*ΔPACD_WA*	
C	0.12	2.12*	0.05	2.44	0.03	2.08**	0.05	1.75	0.08	2.19**	0.08	2.05*	0.05	3.79***
ΔMS_t	0.08	0.44	0.09	1.28	0.51	3.18***	0.08	0.86	0.21	1.39	0.14	0.67	0.86	1.89***
ACD_{t-1}	-1.05	-4.31***	-0.07	-0.61	-0.51	-3.09***	-0.15	-1.32	-0.74	-4.77***	-0.76	-2.18**	-0.93	-3.73***
MS_{t-1}	0.45	2.66**	-0.16	-2.28**	0.29	1.95*	0.03	0.28	0.54	4.30***	0.21	0.99	-0.26	-0.39
Adj. R-squared	0.58		0.38		0.36		0.05		0.37		0.13		0.70	
F-stat.	6.87***		5.44***		1.95		1.58		7.58***		1.64		10.2***	
F-stat. H_0: $\pi_1=\pi_2=0$	10.31		4.40		4.77		1.74		11.37		2.39		9.28	
LM test (F-stat)	2.50		0.24		1.17		0.00		9.51***		0.01		2.19	
N	14		23		32		32		35		14		13	

6 Conclusions and implications

This analysis forms the starting point of an empirical paradigm which uses time series data describing economic network variables for the study of the relationship between the horizontal and vertical dimensions of industry structure and dynamics.

With respect to the tradition of use of the network concept and techniques in industrial economics, we propose new directions in three respects. First, we focus on vertical relations rather than horizontal agreements. Second, it is not only the structure of networks which is investigated but the dynamics over time as well. Third, we explore the linkage between the dynamics of networks and industrial dynamics (for an initial suggestion in this direction see Orsenigo et al., 1998, 2000).

We made some substantive assumptions regarding the process underlying the creation of linkages and the distribution of quantities, which derive from theories of industrial dynamics applied to specific industry contexts. The econometric analysis supports many of the hypotheses and highlights interesting differences between jet and turboprop markets.

In the jet market, characterised by the presence of a competitive core in the network, concentration is negatively related to the density of the core and positively related to the group centralisation, while in the turboprop industry concentration is explained only by density. These findings reflect differences in the competitive regimes of the two markets. Both are oligopolistic, but the jet engine industry experienced a marked intensification of competition and a decline in the level of concentration. At the firm level, the relation between actor centrality and market shares is significant in many cases. In the turboprop industry, the relation is more significant, as the size distribution of the downstream industry is less skewed.

A promising future research direction is the reformulation of several concepts in industrial dynamics (including technological regimes and market demand regimes) in terms of the implied relations between network measures and industry measures.

Admittedly, this approach can be adopted mainly for industries that sell industrial products, in which the number of producers and customers can be quantified reasonably accurately. Although this is a limitation, it is worth recalling that industrial markets account for the majority of value added at the world level. In addition, the approach can be used for consumer industries in which the retail trade sector is concentrated.

A possible objection to our proposed methodology might stress that the use of relational concepts and measures ignores the oligopolistic nature of the two industries, with just a few actors playing strategically in the market. As was shown in the paper, in industries which display great stability in the number of players and in the pattern of entry and exit, the analysis of relational dynamics provides additional and more detailed information about industry structure and dynamics, and in particular about the dynamics of market shares. In a sense, network measures allow identification of the turbulence which takes place in deep waters, under a possibly quiet surface of a stable number of competitors. Therefore, the combination of network measures with industrial dynamics measures we are proposing can be thought as a *structural* approach, which might be an attractive alternative to over-strategizing, fragile, game-based representations.

Appendix 1. List of Companies

		TURBOJET	**TURBOPROP**
Engine Manufacturers			
AE	Allison	✓	✓
CI	CFM International	✓	
GA	Garrett		✓
GE	General Electric	✓	✓
IA	International AeroEngines	✓	
PW	Pratt & Whitney	✓	✓
RR	Rolls Royce	✓	✓
TX	Textron	✓	
TU	Turbomeca		✓
WA	Walter		✓
Aircraft Manufacturers			
AIR	Airbus	✓	
ARO	Aerospatiale (-Alenia)	✓	✓
BAE	British Aerospace	✓	✓
BEE	Beech		✓
BOE	Boeing	✓	
BOM	Bombardier	✓	
CAS	Casa		✓
CON	Convair		✓
DAS	Dasa	✓	
DHC	De Havilland Company		✓
DOR	Dornier	✓	✓
EMB	Embraer	✓	✓
FAI	Fairchild		✓
FOK	Fokker	✓	✓
HAN	Handley Page		✓
HAW	Hawker Siddeley	✓	✓
IPT	IPTN		✓
LET	Let		✓
LOC	Lockheed	✓	✓
MDC	Mc Donnell Douglas	✓	
NAM	Namc		✓
NOR	Nord		✓
PIL	Pilatus		✓
ROM	Rombac	✓	
SAA	Saab		✓
SHO	Short		✓
VFW	VFW (Vereinigte Flugtechnische Werke)	✓	
VIC	Vickers		✓

Appendix 2. List of variables and summary statistics

Variable	Description	Mean	Max	Min	St dev	n
J_CR2	CR2 – jet engine industry	0.80	1.00	0.51	0.16	40
J_HERF	Herfindahl - jet engine industry	0.47	0.83	0.20	0.21	40
P_CR2	CR2 – turboprop engine industry	0.87	1.00	0.69	0.09	45
P_HERF	Herfindahl – turboprop engine industry	0.54	1.00	0.34	0.20	45
J_MS	Market shares – all jet engine companies	0.25	0.90	0.00	0.24	151
JMS_CI	Market shares – CFM International	0.15	0.37	0.00	0.14	31
JMS_GE	Market shares – General Electric	0.18	0.27	0.00	0.06	28
JMS_PW	Market shares – Pratt & Whitney	0.58	0.90	0.13	0.24	40
JMS_RR	Market shares – Rolls Royce	0.14	0.28	0.04	0.06	40
JMS_TX	Market shares – Textron	0.06	0.11	0.01	0.03	17
P_MS	Market shares – all turboprop engine companies	0.26	1.00	0.00	0.27	163
PMS_AE	Market shares – Allison	0.17	0.61	0.00	0.19	15
PMS_GA	Market shares – Garrett	0.18	0.41	0.07	0.09	24
PMS_GE	Market shares – General Electric	0.08	0.21	0.00	0.06	33
PMS_PW	Market shares – Pratt & Whitney	0.52	0.81	0.01	0.20	33
PMS_RR	Market shares – Rolls Royce	0.46	1.00	0.00	0.35	36
PMS_TU	Market shares – Turbomeca	0.05	0.13	0.01	0.04	15
PMS_WA	Market shares – Walter	0.01	0.05	0.00	0.01	14
J_DENSITY	Density – jet network	0.44	0.67	0.35	0.06	40
J_DENCORE	Density of the core – jet network	0.70	1.00	0.44	0.16	40
J_GC	Group centralisation – jet network	0.39	0.75	0.00	0.16	40
J_GCCORE	Group centralisation the core – jet network	0.50	1.00	0.00	0.30	39
P_DENSITY	Density – turboprop network	0.35	1.00	0.16	0.21	45
P_GC	Group centralisation – jet network	0.46	0.83	0.00	0.19	43
J_ACD	Actor centrality – all jet engine companies	0.24	0.67	0.00	0.14	151
JACD_CI	Actor centrality – CFM International	0.11	0.18	0.00	0.05	31
JACD_GE	Actor centrality – General Electric	0.24	0.33	0.10	0.06	28
JACD_PW	Actor centrality – Pratt & Whitney	0.27	0.50	0.15	0.08	40
JACD_RR	Actor centrality – Rolls Royce	0.39	0.67	0.15	0.16	40
JACD_TX	Actor centrality – Textron	0.08	0.09	0.06	0.01	17
P_ACD	Actor centrality – all turboprop engine companies	0.25	1.00	0.00	0.20	163
PACD_AE	Actor centrality – Allison	0.20	0.40	0.00	0.12	15
PACD_GA	Actor centrality – Garrett	0.18	0.27	0.09	0.05	24
PACD_GE	Actor centrality – General Electric	0.11	0.20	0.00	0.05	33
PACD_PW	Actor centrality – Pratt & Whitney	0.37	0.60	0.10	0.13	33
PACD_RR	Actor centrality – Rolls Royce	0.47	1.00	0.06	0.27	36
PACD_TU	Actor centrality – Turbomeca	0.12	0.17	0.09	0.02	15
PACD_WA	Actor centrality – Walter	0.06	0.09	0.00	0.03	14

This Appendix provides the description of the variables used in the regressions and the summary statistics of the time series data of each variable that may be of interest for the reader. The letter J preceding the variables refers to the jet industry while the letter P to the turboprop industry.

Appendix 3. Critical values for F and t

	F	t
p<0.10	4.78	2.91
p<0.05	5.73	3.22
p<0.01	6.68	3.82

Sources: Pesaran et al. (2000)

Appendix 4. Actor level regression specifications.

The panel includes the market share of each of the *n* firms at time *t* (S_t) as the dependent variable, and the associated actor centrality degree using the more informative method of normalisation (ACD_t) as the independent variable. In model *b* we introduce D*I*, a dummy intercept variable, and D*ACD* and D*S*, the dummies for the independent variables and for the lagged dependent variables, for each *i*-firm. In model *c* we regress separately the market share of each firm.

MODEL *a*

$$\Delta S_t = \alpha + \beta_0 \Delta ACD_t + \pi_1 S_{t-1} + \pi_2 ACD_{t-1} + \varepsilon_t \tag{2}$$

$$\Delta ACD_t = \alpha + \beta_0 \Delta S_t + \pi_1 ACD_{t-1} + \pi_2 S_{t-1} + \varepsilon_t \tag{3}$$

MODEL *b*

$$\Delta S_t = \alpha + \beta_0 \Delta ACD_t + \pi_1 S_{t-1} + \pi_2 ACD_{t-1} + \sum_{i=2}^{n} \beta_{0i} D\Delta ACD_t + \sum_{i=2}^{n} \pi_{1i} DS_{t-1} + \sum_{i=2}^{n} \pi_{2i} DACD_{t-1} + \varepsilon_t \tag{4}$$

$$\Delta ACD_t = \alpha + \beta_0 \Delta S_t + \pi_1 ACD_{t-1} + \pi_2 S_{t-1} + \sum_{i=2}^{n} \beta_{0i} D\Delta S_t + \sum_{i=2}^{n} \pi_{1i} DACD_{t-1} + \sum_{i=2}^{n} \pi_{2i} DS_{t-1} + \varepsilon_t \tag{5}$$

MODEL *c*

$$\Delta S_{it} = \alpha + \beta_0 \Delta ACD_{it} + \pi_1 S_{it-1} + \pi_2 ACD_{it-1} + \varepsilon_t \tag{6}$$

$$\Delta ACD_{it} = \alpha + \beta_0 \Delta S_{it} + \pi_1 ACD_{it-1} + \pi_2 S_{it-1} + \varepsilon_t \tag{7}$$

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