Laboratory of Economics and Management
Sant'Anna School of Advanced Studies

Via Carducci, 40 - I-56127 PISA (Italy)
Tel. +39-050-883-341 Fax +39-050-883-344
Email: lem@sssup.it Web Page: http://lem.sssup.it

LEM
Working Paper Series

Non ergodic properties of the dynamics of industry concentration

A. Bonaccorsi[*]
R. Cambini [†]
P. Giuri[*]
and
R. Riccardi[†]

[*] *Sant'Anna School of Advanced Studies, Pisa, Italy*
[†] *Department of Statistics and Applied Mathematics,*
Faculty of Economics, University of Pisa, Italy

2001/12 **August 2001**

ISSN (online) 2284-0400

NON ERGODIC PROPERTIES OF THE DYNAMICS OF INDUSTRY CONCENTRATION

A. Bonaccorsi♣, R. Cambini♦, P. Giuri♣, R. Riccardi♦

♣bonaccorsi@sssup.it, giuri@sssup.it
Sant'Anna School of Advanced Studies
Laboratory of Economics and Management
via Carducci, 40 – 56127 Pisa, Italy
♦ cambric@ec.unipi.it, roxane.riccardi@katamail.com
University of Pisa
Department of Mathematics and Statistics for Economic Studies
via Ridolfi 10, 56124 Pisa, Italy

JEL classification: L13, L19, L22, L63

First Draft August 2001

1. Introduction

The long-run evolution of industry concentration has been a primary concern in industrial dynamics. In general it is difficult to analyse the final outcome of industry evolution in terms of concentration, unless a great deal of detail is added to the technological and institutional description of the industry.

We propose that the structural evolution of concentration can be predicted by studying the joint evolution of two vertically-related industries, i.e. a supplier and a buyer industry. In particular a summary statistics of the structure of relations between two industries is given by the density of the network as the total number of relations between each individual buyer and supplier divided by the maximum number of potential relations.

We build a mathematical model of the relation between density of a network connecting two vertically-related industries, i.e. a supplier and a buyer industry, and the concentration of the supplier industry in the long run. The paper develops an application of Markov-chain models in the evolutionary dynamics of vertically-related industries.

Some hypotheses on the existence of a relation between economic network time series and industrial dynamics have been tested by using a co-integration model in a related paper (Bonaccorsi and Giuri, 2001a). Results of the econometric analysis supported the hypothesis of a positive relation between network density and concentration in industries characterised by the presence of asymmetric distribution of vertical relations across actors, while a negative relation in industries characterised by symmetric relational positions of actors.

By using a Markov-chain model, in this paper we find much stronger results for the existence of a structural relation between density and concentration. This is quite significant as the Markov-chain models are characterised by the looseness of specific assumptions on the structure and distributions of data, and on their evolution over time. In fact the model is memory-less, and observations over time are all independent on each other.

The model is applied to the long-term evolution of the aircraft and aero-engine industries. These two industries are interesting from an evolutionary perspective, as their boundaries have been stable over their history, so that the co-evolution can be observed accurately. We use a proprietary database that we built on several sources of data (Atlas Aviation database, Jane's All the World Aircraft 1940-1998, Jane's Aero-engines 1997), containing all market shares of aircraft and aero-engine companies and all vertical transactions among them from 1948 to 1997 in two markets (jet and turboprop).

For the two markets, we calculate annual indicators of density of the network of vertical relations between aircraft and engine manufacturers (respectively buyer and supplier industry) and annual Herfindahl indexes of concentration of the supplier industry.

Markov-chains with discrete and finite states are built in three cases with the following couples of variables: density and concentration in the jet industry (case 1), density and concentration in the turboprop industry (case 2), density of the core of the network and concentration in the jet industry (case 3). In the latter case the core is defined as the sub-graph of the network composed of all actors having at least 2 relations with all other actors in the sub-group.

We study the joint evolution of the two variables and find that with very large probabilities measures the system converges in the long run in a small region of the space of possible states.

In the three cases the results show (i) the convergence of the jet industry towards a low level of density and concentration; the convergence of the turboprop industry toward a low level of density and variable levels of industry concentration; the presence two absorbing states of high density of the core and low concentration in the jet industry.

The latter result is even more interesting. Recall that Markov-chains by definition do not impose any structure on the evolution. Still, in the case of the core of the industry, we find that the Markov chain exhibits non ergodic properties and the final state is an absorbing one.

We propose that *the network is an intermediate economic structure*, which cannot be reduced to the industry level or to the firm level but has its own theoretical and empirical status.

The topological properties of the network have a major influence on the way in which the dynamics of the network itself and the dynamics of the industry jointly evolve. In particular, the topological property of the core is responsible for large long run effects, even of non-ergodicity in the dynamics.

2. Industry and network variables

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 (see Malerba et al., 1998; for a model of the computer industry, in which 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”.

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).

We develop a Markov chain model of the joint evolution of industry concentration and density of the network of vertical relation commercial aircraft and aero-engine industries (see Appendix 1 for a description of data used in the empirical analysis). The model is developed in the two markets for jet and turboprop aero-engines. In the jet industry, characterised by the emergence of a dense core in the network, we also study the joint evolution of industry concentration of industry concentration and density of the core.

2.1 Definition of variables

For the purpose of this analysis we choose, among several possible network measures, to use the relational density as a simple summary statistics of the vertical relations between a supplier and a buyer industry. For two oligopolistic industries like the aircraft and aero-engines, characterised by a small number of players, and therefore by a small size of the network, a simple measure like density meaningfully summarises changes in relational patterns. We also detect the existence of dense sub-group of the network (core) and compute an indicator of density of the core.

Network measures 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, 1999a, 1999b; Asratian et al., 1998).

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 the measure of *relational density* for disentangling the effects on concentration of, respectively, the relational activity of individual firms and the dynamics of quantities.

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.

$$DENSITY = \frac{\sum_{i}^{N} rij}{N * M}$$

i=1,2,…, N
j=1,2,…, M

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.

At the aero-engine industry level we compute the Herfindahl index of concentration.

$$HERF = \sum_{i=1}^{N} S_i^2$$

S_i= market shares of *i*-firms

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. 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 programs.

In related papers Bonaccorsi and Giuri (2000a, 2000b, 2001b) studied the history and structural evolution of the networks respectively in the jet and turboprop industries. The network analysis shows that the level of relational density in the turboprop is always lower than in the jet. Moreover, the jet network is characterised by the emergence and expansion of a core of highly connected actors and a periphery of disconnected actors and of actors with only one relation in the core. On the contrary in the turboprop there is no emergence of a core, the A matrix is more sparse and the network is partitioned as it is characterised by presence of relations which are mainly one-to-one. The economic reasons for the formation and evolution of different network structures in the two markets are the differences in the level of economies of scope, of technological cospecialisation between engine and aircraft products, the level of market segmentation, and the sourcing strategies of aircraft manufacturers (Bonaccorsi and Giuri, 2001b).

In this paper we use time series of density and concentration from 1953 to 1997 in the two industries and Markov chain models in order to study their joint evolution. The time path of the joint evolution of the variables is graphically shown in Section 4.

3. Description of the Markov Chain Approach

Our aim is to study the considered engine industry models, related to the jet engines and the turboprop engines, by means of discrete Markov Chains. In this way, it is possible to determine the behaviour of the models in the long-term by means of the analysis of the asymptotic properties of the transition matrix associated to the chain.

For the two markets, we calculate annual indicators of density of the network of vertical relations between aircraft and engine manufacturers (respectively buyer and supplier industry) and annual Herfindahl indexes of concentration of the supplier industry.

These indicators are real values in the interval [0,1] and the states of the Markov chains are determined splitting the interval into segments.

First, the interval [0,1] is splitted into 5 equally wide segments for both the density and the Herfindahl index, thus obtaining 25 different states given by the combinations of the segments. The long-term analysis of the chain gives a preliminary idea of the evolution of the industry. By means of the obtained results, it is possible to state a second chain with 9 states, by splitting the interval [0,1] into 3 non equally wide segments for both the density and the Herfindahl index, having the following properties:

- 8 states are transient while one is absorbing,
- the intervals characterising the absorbing state are as narrow as possible.

In this way it is possible to determine the smallest intervals of density and concentration the industry converges to.

3.1 Preliminary study

The interval [0,1] is splitted into the following five (non closed) segments for both the density and the Herfindahl index:

H1=D1= [0,1/5],
H2=D2=]1/5,2/5],
H3=D3=]2/5,3/5],
H4=D4=]3/5,4/5],
H5=D5=]4/5,1],

thus obtaining 25 states given by the combinations of the segments themselves.

For the defined classes we determine the transition probabilities, according with the dynamics of the serie. Not all the 25 states are used, so that the unused ones are left over obtaining smaller chains. The obtained results are as follows.

Jet Industry

The remained 9 states are the followings (in fixed ordering):

[H1, D2], [H2, D2], [H2, D3], [H3, D2], [H3, D3],
[H4, D2], [H4, D3], [H4, D4], [H5, D3]

and the related Markov chain is given by the following transition matrix:

$$P_{jet} := \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1/12 & 2/3 & 1/6 & 1/12 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/7 & 0 & 4/7 & 2/7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2/9 & 2/3 & 0 & 1/9 & 0 & 0 \\ 0 & 1/2 & 0 & 0 & 0 & 1/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/4 & 1/2 & 1/4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

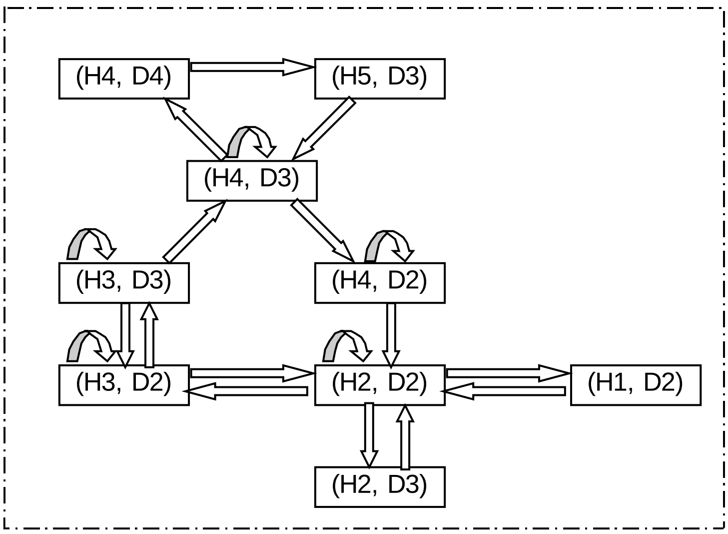

Figure 1 Markov-chain, *jet industry*

The second greater eigenvalue of Pjet, in absolute value, is μp=0.8404443204, hence for Theorem A1 the stochastic matrix Pjet is semiconvergent and its asymptotic behaviour is $\lim_{k\to+\infty}\left(P_{jet}\right)^k = \mathrm{u}d^T$ where $\mathbf{u} = (1,1,\ldots,1,1)^T \in \Re^n$ and

d^T=[1/26, 6/13, 1/13, 21/130, 9/65, 2/65, 4/65, 1/65, 1/65]

Note that the matrix is indecomposable and all the states are recurrent (the chain results to be ergodic). In order to better view the results, let us provide the long-term probabilities in the following table:

Jet	Dens 0.0-0.2	Dens 0.2-0.4	Dens 0.4-0.6	Dens 0.6-0.8	Dens 0.8-1.0
Herf 0.0-0.2	0	0.038	0	0	0
Herf 0.2-0.4	0	0.462	0.077	0	0
Herf 0.4-0.6	0	0.162	0.138	0	0
Herf 0.6-0.8	0	0.031	0.062	0.015	0
Herf 0.8-1.0	0	0	0.015	0	0

We can easily see that in the 84% the industry converges in the long term towards a density and a concentration in the interval [0.2-0.6], and the 46.2 % in the interval [0.2-0.4].

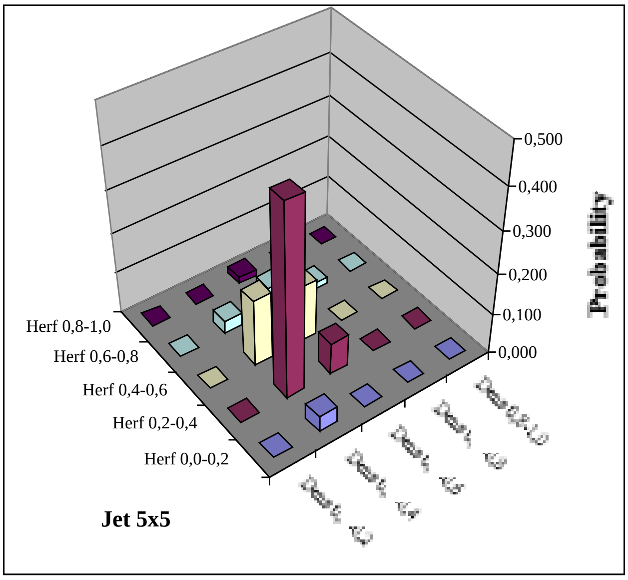

Figure 2 Long-term probabilities, *jet industry*

Turboprop Industry

The remained 10 states are the followings (in fixed ordering):

[H2, D1], [H2, D2], [H3, D1], [H3, D2], [3H, D3],
[H4, D2], [H4, D3], [H5, D2], [H5, D3], [H5, D5]

and the related Markov chain is given by the following transition matrix:

$$P_{prop} := \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1/6 & 7/12 & 0 & 1/4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/7 & 1/14 & 9/14 & 0 & 1/7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2/3 & 0 & 1/3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 1/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2/3 & 1/3 \end{bmatrix}$$

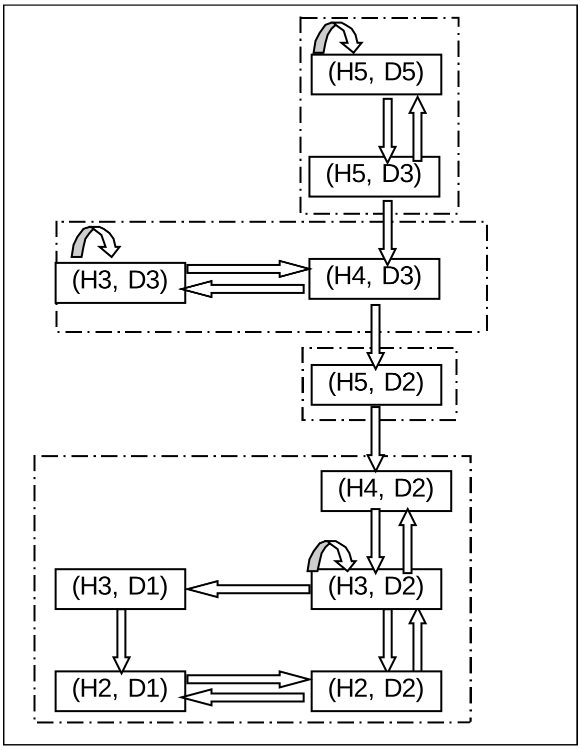

Figure 3 Markov-chain, *turboprop industry*

The second greater eigenvalue of Pprop, in absolute value, is μp=0.8603796101 and again Pprop is semiconvergent and its asymptotic behaviour is $\lim_{k \to +\infty} (P_{jet})^k = \mathrm{u} d^T$ where $\mathbf{u} = (1,1,\ldots,1,1)^T \in \Re^n$ and

d^T=[3/32, 3/8, 1/32, 7/16, 0, 1/16, 0, 0, 0, 0]

Note that the matrix is decomposable and some of the states are transient (the chain is not ergodic). The long-term probabilities can be represented in the following table:

Prop	Dens 0.0-0.2	Dens 0.2-0.4	Dens 0.4-0.6	Dens 0.6-0.8	Dens 0.8-1.0
Herf 0.0-0.2	0	0	0	0	0
Herf 0.2-0.4	0.094	0.375	0	0	0
Herf 0.4-0.6	0.031	0.438	0	0	0
Herf 0.6-0.8	0	0.063	0	0	0
Herf 0.8-1.0	0	0	0	0	0

We can easily see that in the 81% the industry converges in the long term towards a density in the interval [0.2-0.4] and a concentration in the interval [0.2-0.6].

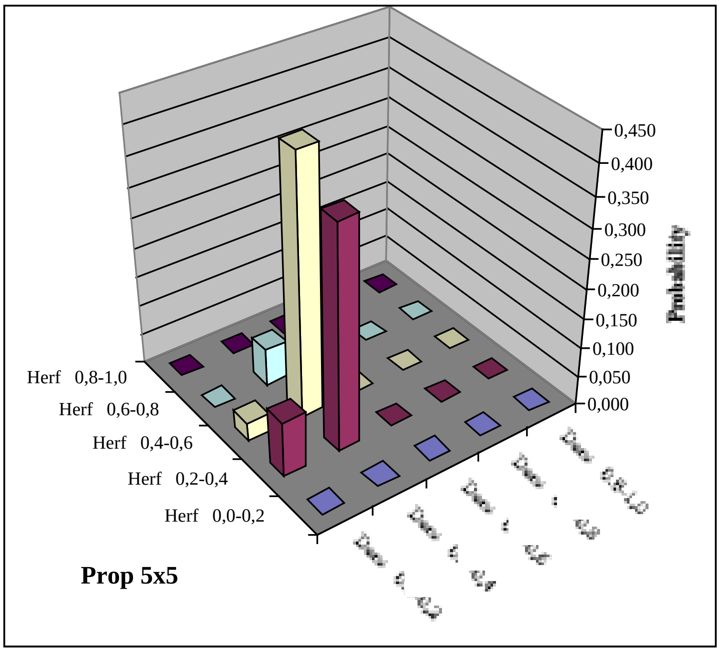

Figure 4 Long-term probabilities, *turboprop industry*

Jet Industry - Core

The remained 10 states are the followings (in fixed ordering):

[H1, D5], [H2, D3], [H2, D4], [H2, D5], [H3, D3],
[H3, D4], [H3, D5], [H4, D3], [H4, D4], [H5, D4]

and the related Markov chain is given by the following transition matrix:

$$P_{core1} := \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2/3 & 0 & 1/3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/10 & 4/5 & 1/10 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 4/7 & 2/7 & 1/7 & 0 & 0 & 0 \\ 0 & 1/4 & 0 & 0 & 1/4 & 1/2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/5 & 0 & 3/5 & 0 & 1/5 & 0 \\ 0 & 1/3 & 0 & 0 & 0 & 0 & 0 & 2/3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/4 & 1/2 & 1/4 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

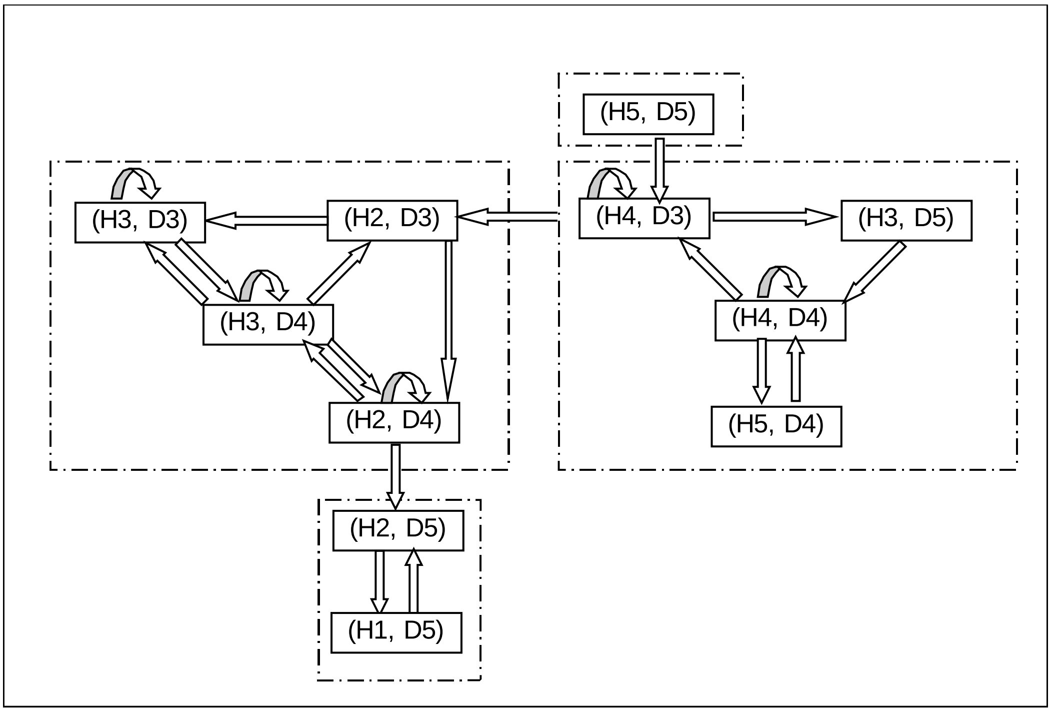

Figure 5 Markov chain, *jet industry - core*

The second greater eigenvalue of Pcore1, in absolute value, is μp=1 hence the matrix is not semiconvergent and the chain in the long-term is periodic among the two recurrent states

[H1,D5] and [H2,D5]. As a consequence, the long-term probability for these two states is 0.5; in other words the whole industry converges in the long term towards a density in the interval [0,8-1] and a concentration in the interval [0-0,4].

3.2 Further Developments

In order to deep on the behaviour of the industry, we now want to determine the values Hmin, Hmax, Dmin, Dmax∈[0,1] such that the intervals

H1=[0,Hmin[H2=[Hmin, Hmax] H3=]Hmax, 1]
D1=[0,Dmin[D2=[Dmin, Dmax] D3=]Dmax, 1]

provide a Markov chain having the following properties:

- a long-term probability for the state (H2,D2) equal to 1
- if we slightly modify the intervals by means of a small real value ε>0 the long-term probability for the state ([Hmin+ε, Hmax-ε], [Dmin+ε, Dmax-ε]) is strictly lower than 1.

In other words our aim is to determine the narrowest intervals for the density and the concentration providing a long-term probability equal to 1. The study is carried on by means of computer simulations done with a symbolic calculus program (Maple™).

Jet Industry

The simulation provides the following data:

Hmin=0.1959737198 Hmax=0.2736682512
Dmin=0.3124999999 Dmax=0.4500000000

Just 3 classes remains in the Markov chain, more precisely:

[H2, D2], [H3, D2], [H3, D3]

and the related Markov chain is given by the following transition matrix:

$$A_{jet} := \begin{bmatrix} 1 & 0 & 0 \\ 1/17 & 14/17 & 2/17 \\ 0 & 3/10 & 7/10 \end{bmatrix}$$

It can be easily seen that the state [H2, D2] is absorbing, hence with a long-term probability equal to 1. This behaviour does not hold considering the state

$$([H_{min}+\varepsilon, H_{max}-\varepsilon], [D_{min}+\varepsilon, D_{max}-\varepsilon])$$

Hence with probability 1 the industry converges towards a density in the interval [0.3125, 0.45] and a concentration in the interval [0.196, 0.274].

Turboprop industry - core

The simulation provides the following data:

Hmin=0.3389139809 Hmax=0.665360848
Dmin=0.1249999999 Dmax=0.340909091

Just 4 classes remains in the Markov chain, more precisely:

[H2, D2], [H2, D3], [H3, D2], [H3, D3]

and the related Markov chain is given by the following transition matrix:

$$A_{prop} \coloneqq \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 2/3 & 0 & 1/3 \\ 0 & 0 & 0 & 1 \\ 1/8 & 1/8 & 1/8 & 5/8 \end{bmatrix}$$

It can be easily seen that the state [H2, D2] is absorbing, hence with a long-term probability equal to 1. This behaviour does not hold considering the state

$$([H_{min}+\varepsilon, H_{max}-\varepsilon], [D_{min}+\varepsilon, D_{max}-\varepsilon])$$

Hence with probability 1 the industry converges towards a density in the interval [0.125, 0.34] and a concentration in the interval [0.34, 0.665].

Jet Industry - Core

The simulation provides the following data:

Hmin=0.1959737199 Hmax=0.2078517958

Dmin=Dmax=0.833

Just 3 classes remains in the Markov chain, more precisely:

[H2, D2], [H3, D1], [H3, D3]

and the related Markov chain is given by the following transition matrix:

$$A_{core1} := \begin{bmatrix} 1 & 0 & 0 \\ 1/32 & 15/16 & 1/32 \\ 0 & 2/5 & 3/5 \end{bmatrix}$$

It can be easily seen that the state [H2, D2] is absorbing. This behaviour does not hold considering the state

([Hmin+ε, Hmax-ε], [Dmin, Dmax])

Hence with probability 1 the industry converges towards a density equal to 0.833 and a concentration in the interval [0.196, 0.208].

Results of the three cases are summarised in Figure 6.

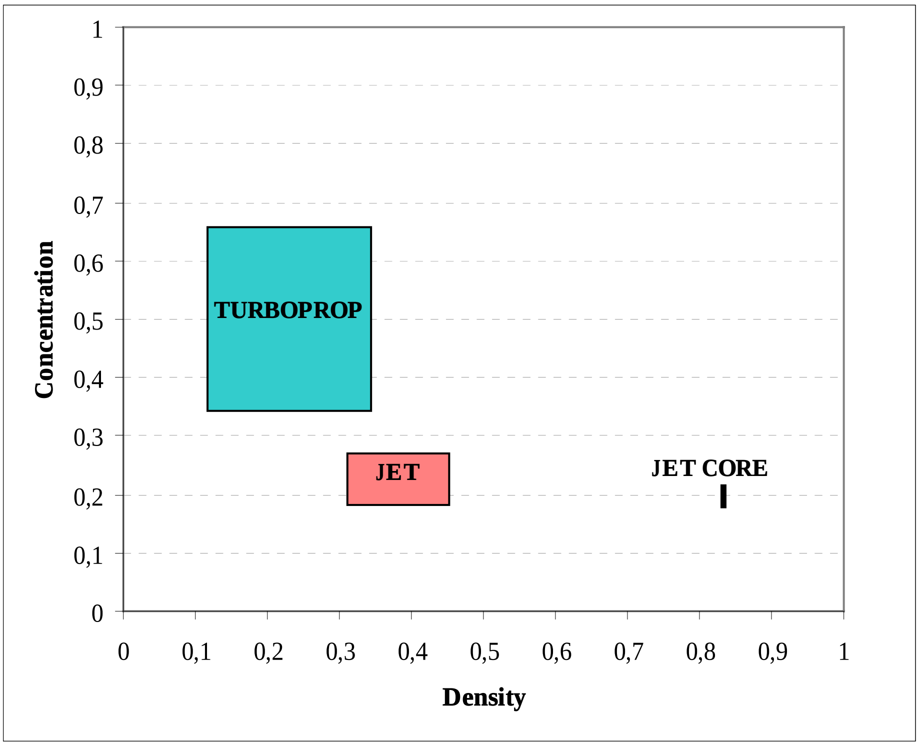

Figure 6 Simulation results of long-term probabilities

4. Interpretation of results

To ease the interpretation of results, we show in Figures 7-9 the scatters of the time path of the couples density-concentration in the jet and turboprop industries.

In the jet industry, we may observe an early period (from 1958 to 1970) characterised by large oscillation in the levels of both density and concentration. The increase in concentration reflects the growth of the dominant leader and the decline in density is caused by the entry of actors with only one relation (Figure 7). Soon after concentration decreased due to the growth of the entrants and oscillated until the beginning of the 1980s in a range of 0.4-0.6. In the same period density oscillated in a range of 0.3-0.5 due to the increasing relational activity of large incumbents, which expanded the core of the network and to the entry of players at the periphery with a number of relations below the average. The final period, after 1984, was marked by a further reduction of the level of concentration to 0.2, reflecting the intense competition among incumbents and by a persistently oscillating level of density due to the intensification of relational activity in the core and the expansion of the periphery.

It is very interesting to compare this dynamics with the evolution of the couple density of the core-concentration in the jet industry, as depicted in Figure 8. In the first period the oscillations of density are amplified, due to the small number of actors in the core and the stronger effect on the index of each variation in terms of relations. After 1972 the density of the core declines for the entry of new actors in the core and then, with some smaller fluctuation, follows a clear increasing pattern for the intensification of relations, reaching the value of 0.833. At the same time concentration steadily declines.

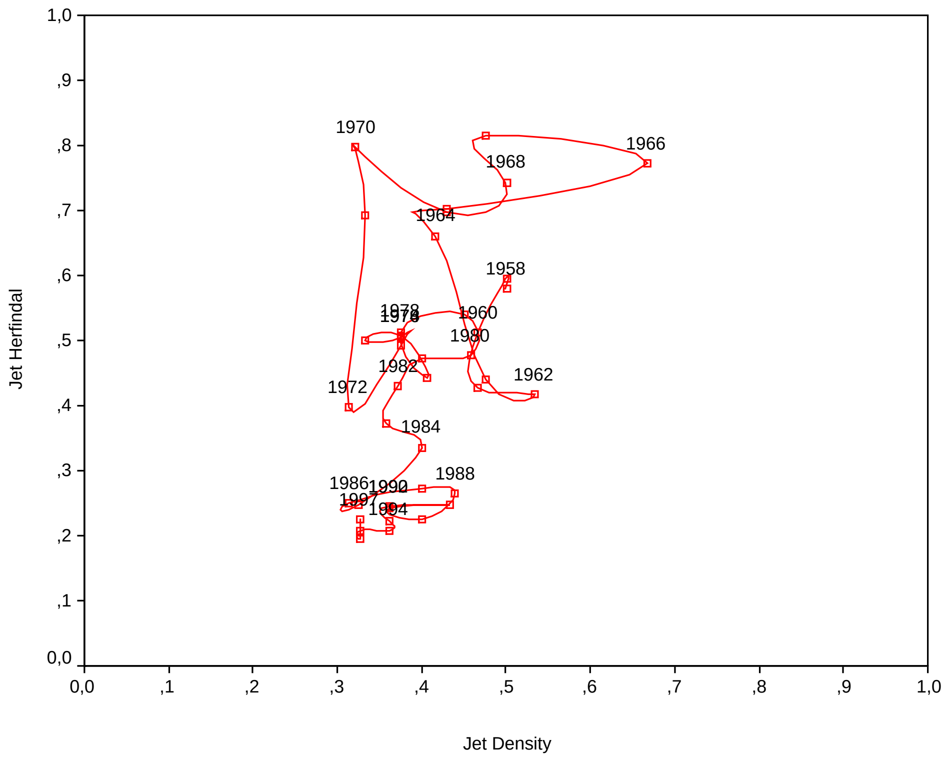

Figure 7 Time path of density-concentration, *jet*

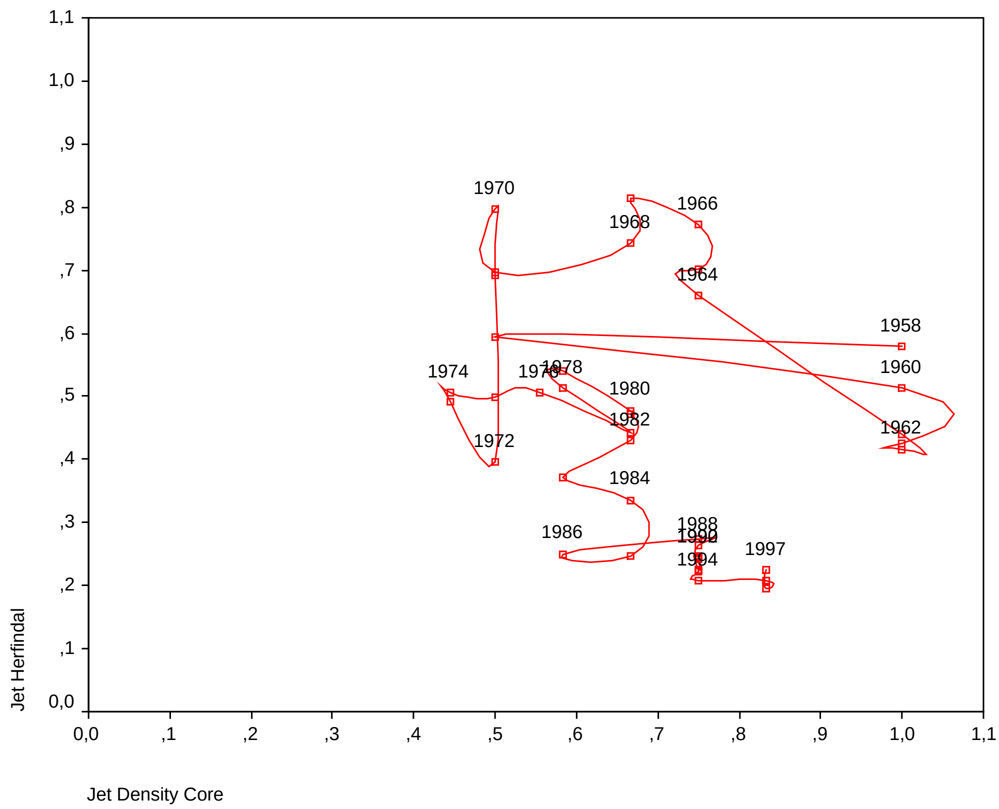

Figure 8 Time path of density of the core-concentration, *jet*

In the turboprop industry the pattern is marked by fluctuations both in density and concentration until 1965, due to strong competition in the duopoly created by the first entrants in the aero-engine market (and to stronger effects due to the small number of actors). After 1965, the density and concentration fluctuate in a bounded area (0.3-0.7 for concentration and 0.1-0.4 for density). The oscillation of the level of concentration reflects the substitution of the leader and the strong competition with followers in different market segments. The level of density fluctuates mainly for entry and exit of players. The absolute level of density is lower than in the jet because relations are mainly one-to-one and there is not emergence of groups of highly connected actors, i.e. there is no core.

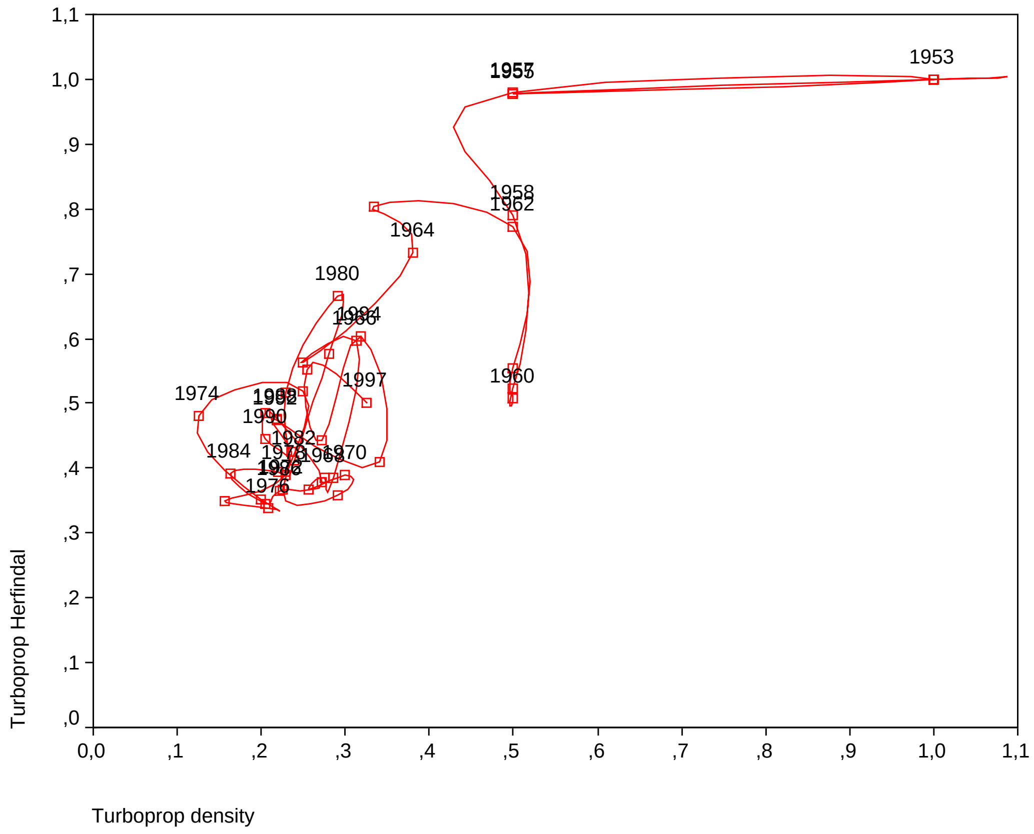

Figure 9 Time path of density-concentration, *turboprop*

The analysis of transition probabilities and the inspection of the time path allow to draw some important implications on structural characteristics of industrial dynamics.

To start with, there are some elements in common in both industries.

First, throughout the entire dynamics, *the system explores a limited region* of the space of states defined by couples of concentration-density measures. This is particularly true for density, for which the range of values explored by the system (with the exception of initial years in turboprop) is quite narrow. In terms of cells of the transition probabilities matrix, one can observe a strong concentration in a limited number of cells.

Second, the time path shows that *the initial years of both industries are characterised by unstable states*, i.e. states that are abandoned afterwards. In the jet industry, the years 1958-62 were characterised by intermediate levels of concentration and high level of density; concentration increased sharply in the period 1963-68, then declined abruptly until 1972. Then the system oscillated in a region characterised by density values around 0.4 and Herfindahl values around 0.5, and finally collapsed into the final region. The region of initial years was touched upon only in 1980, but then the system followed a diverse trajectory. This pattern is even more pronounced in the turboprop industry. In the initial period 1956-63 one can observe the system moving in a region characterised by extremely high values of density, which will not be reached any longer in the subsequent evolution.

Third, *the dynamics collapses into a limited region of the state space*. In both industries the system will converge with high probability into two regions characterised by a narrow range of variables. In the jet industry with probability 0.462 the system will move into the region (D2, H2); in the turboprop with probability 0.438 into the region (D2, H3). In the long run both systems converge into a limited area with slightly less than half of total probability. This is a remarkable result, insofar as it tells that, without imposing any a priori causal or structural model, one can still identify an ordered pattern in the long run dynamics. The final states are *stable configurations* of the industry in the joint space density-concentration.

These findings lead us to confirm the theory. The dynamics of vertical networks and the dynamics of structural evolution of the industry are jointly determined. The former constrains the latter and viceversa. After some initial random exploration, the system of joint structural states converges into a fairly narrow region of the state space. There are stable configurations in the long run.

There are also important differences between the two industries that deserve close scrutiny. Two points are remarkable. First, the final region is much *narrower* in the jet industry than in the turboprop. In the jet case the industry converges with probability 1 towards a density in the interval (0.3125 - 0.45) and a concentration in the interval (0.196 – 0.274). In the turboprop the corresponding intervals are (0.125 - 0-34) for density and (0,34 - 0.665) for concentration. As it can be seen, the interval is very narrow for concentration in the jet, much larger in the turboprop. Figure 6 illustrates this point graphically.

Second, while both Markov chains are ergodic, the chain associated to the core of the network in the jet industry is *non-ergodic*. This is another remarkable finding. There are not many examples of non-ergodic dynamics in economic phenomena, even less in industrial dynamics.

Our interpretation of the findings is as follows. The striking difference in the two dynamics can be explained through reference to the *topological characteristics of the networks*. In the turboprop there is *not* a core in the network, while in the jet industry it was formed very early in the history of the industry. As it was discussed in Bonaccorsi and Giuri (2001b), the existence of a core means that the transmission of effects from the downstream industry (the aircraft or customer industry) to the upstream industry is channelled through a structure that absorbs and redistributes the perturbations. The presence of a core explains why the final region is very narrow in the jet industry. There are powerful forces that would bring the system back to that region should it diverge.

Let us examine the stability of the final configuration in the jet industry in the region (H2, D2). A lateral shift on the left, towards a region with less density, would mean that the number of relations within the core should diminish drastically. In fact, a reduction in the number of relations in the periphery would not have much impact, since most of them are one-to-one and the associated market shares are small (hence the elimination of relations would mean elimination of actors, with an *increase* in density). Another possibility would be a new entry, but the impact on density would not be large, since the region is characterised by a low average number of relations per actor and a new entrant with just one relation would not cause a major decrease. Therefore the only possibility is a major destabilisation of the core of the network, which is not likely.

A lateral shift on the right (increase in density) would require either the exit of firms with a small number of relations, or an increase in the average number of relations per actor. Since actors in the core already have many relations, this is possible only in the periphery. The exit of firms from the periphery is not unlikely, but it would not change density dramatically. The increase in the average number of relations means that actors in the periphery multiply their supply relations, which is to say, enter the core. This is highly unlikely, given the structural properties of the core and the long run process of its formation, growth and stabilisation. Once again, this lateral shift is not impossible but is certainly highly unlikely given the existence of a core.

Finally, consider an upward movement towards a region of higher concentration. Given the existence of the core, this would be possible only with the *exit* of actors from the core itself. In practice, this might mean either bankruptcy and exit, or merger and acquisition. Again, this is not impossible in principle, but is not very likely.

In sum, the final region is a stable configuration because any deviation from it would only follow from a disruption of the core and a major restructuring of the industry.

This is not the case for the turboprop industry in which a core does not exist. There the final region is much larger, meaning that the system may oscillate perpetually between several states. Any perturbation, even of small magnitude, would be reflected in rather large variations in density and concentration, with a full transmission of effects. In fact, in a sparse network, any change in relations, for example the exit or entry of a customer, 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 existence of a core in the network is a powerful stabilising device in the dynamics of bilaterally oligopolistic industries.

The core acts as a governance mechanism for bilateral and multilateral interdependence. All large buyers and large suppliers keep the configuration stable, because the existence of the core regulates their interdependencies in the face of extreme market and technological uncertainty.

No buyer has the interest to eliminate or deprivate any supplier, because it is in its long term interest to keep sufficient R&D and productive capacity available, and to keep competition among suppliers. Buyers accept the extra costs associated to procuring from all large suppliers. No seller has the interest to concentrate its sales on a few customers, because of excess correlation of risks deriving from extreme market uncertainty. Once formed, the core is rather stable. Entry in the core is extremely difficult, exit from the core is also very unlikely. The demography of entry and exit may still take place at the periphery of the network, but its structural effects are modest in the long run.

5. Conclusions

As it is well known from industrial organisation, models of bilateral oligopoly are rather undetermined with respect to the formation of equilibrium prices and make large reference to the theory of bargaining, and then require a lot of fine details to describe the context. In practice, this mean that a robust theory of bilateral oligopoly is not available. Furthermore, no theory is crafted in dynamic terms.

We have provided evidence of a robust dynamic effect in an industry characterised by bilateral oligopoly. The topological properties of the vertical network influence the kind of dynamics observed in the long run. If a core exists, then the industry converges into a stable configuration which is a narrow region of the state space. The core itself exhibits an absorbing state and a non-ergodic dynamics. If a core does not exist, then the industry oscillates between several states in a larger region with no absorbing state.

We propose that *the network is an intermediate economic structure*, which cannot be reduced to the industry level or to the firm level but has its own theoretical and empirical status.

The topological properties of the network have a major influence on the way in which the dynamics of the network itself and the dynamics of the industry jointly evolve. In particular, the topological property of the core is responsible for large long run effects, even of non-ergodicity in the dynamics.

Networks are then candidates as building blocks for a theory of industrial dynamics which considers vertically related structures as the main element of interest.

Appendix 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

[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.

(in particular, *Flight International* and *Aviation Week and Space Technology*) and literature on the history and technological development of the aviation industry[2].

Appendix 2. Mathematical model

The aim of this appendix is to summarise the main mathematical tools used in the paper (see for example Berman and Plemmons, 1994). First of all, let us recall that every finite state Markov chain is defined by means of a stochastic transition matrix.

Definition A1 Let $\mathbf{u} = (1,1,\ldots,1,1)^T \in \Re^n$; a nonnegative matrix $A \in \Re^{n\times n}$, that is $A = (a_{ij})$ with $a_{ij} \geq 0 \ \ \forall i, j \in \{1,\ldots,n\}$, is said to be *stochastic* if

$$A\mathbf{u} = \mathbf{u} \ .$$

For the Brauer-Solow conditions, the maximal eigenvalue of a stochastic matrix A is

$$\lambda_A = 1$$

and it is straightforward from the definition that $\mathbf{u}$ is an eigenvector corresponding to λ_A . Another important property for the maximal eigenvalue of a stochastic matrix is that

$$\sigma(\lambda_A) = \tau(\lambda_A),$$

where $\sigma(\lambda_A)$ and $\tau(\lambda_A)$ denote the algebraic and geometric multiplicity of λ_A , respectively.

A fundamental key tool in the study of stochastic matrices is the second largest of the moduli of their eigenvalues.

Definition A2 Given a nonnegative matrix $A \in \Re^{n\times n}$ with maximal eigenvalue λ_A we define

$$\mu_A = \max_{\lambda\in\Lambda,\lambda\neq\lambda_A} |\lambda|$$

---

[2] Among others, Miller and Sawers, 1968; Phillips, 1971; Constant, 1980; Bright, 1981; Mowery and Rosenberg, 1982, 1989; Hayward, 1986, 1994; Vincenti, 1990; Sutton, 1998; U.S. International Trade Commission, 1998.

where Λ is the set of eigenvalues of A. If $\exists \lambda \in \Lambda$ such that $\lambda \neq \lambda_A$ then we assume $\mu_A = 0$.

The long period properties of a markov chain are given by the asymptotic behaviour of the corresponding transition matrix, for this reason we are interested in the semiconvergence of stochastic matrices.

Definition A3 A nonnegative matrix $A \in \Re^{n\times n}$ is said to be *semiconvergent* if

$$\exists B \in \Re^{n\times n} \text{ such that } \lim_{k\to+\infty} A^k = B$$

Theorem A1 *Let $A \in \Re^{n\times n}$ be a stochastic matrix and let $\lambda_A = 1$ be its maximal eigenvalue. Then matrix A is semiconvergent if and only if*

$$\mu_A < 1.$$

Matrix $B = \lim_{k\to+\infty} A^k \neq 0$ results to be stochastic too and in particular it is $B = MN^T \neq 0$ where $M, N \in \mathbf{C}^{n\times\sigma(\lambda_A)}$ have no zero columns and verify the following properties:

- $N^T M = I_{\sigma(\lambda_A)}$,
- *the columns of M are $\sigma(\lambda_A)$ linearly independent eigenvectors of A corresponding to λ_A ,*
- *the columns of N are $\sigma(\lambda_A)$ linearly independent eigenvectors of A^T corresponding to λ_A .*

If in addiction it is $\sigma(\lambda_A) = 1$ then it results $B = \lim_{k\to+\infty} A^k = \mathbf{u}d^T \geq 0$ where

$$d \in \Re^n,\ d \geq 0,\ \mathbf{u}^T d = 1,\ \left(A^T - I\right)d = 0,$$

while if A is also indecomposable then $d > 0$ and hence $B = \mathbf{u}d^T > 0$.

References

Asratian, A.S., Denley, T.M.J., Haggkvist, R., 1998. Bipartite Graphs and their Applications. Cambridge University Press, Cambridge.

Bain, J.S., 1968. Industrial Organisation. Wiley.

Berman A. and R.J. Plemmons, 1994, Nonnegative matrices in the mathematical sciences, Classics in Applied Mathematics, vol.9, SIAM, Philadelphia.

Bonaccorsi Giuri 2001a, Network structure and industrial dynamics. The long term evolution of the aircraft-engine industry, Structural Change and Economic Dynamics, 12, 201-233.

Bonaccorsi, A., Giuri, P., 2000a, Non shakeout patterns of industry evolution. The case of the turboprop engine industry. Research Policy 29, 847-870.

Bonaccorsi, A., Giuri, P., 2000b, Industry life cycle and the dynamics of the industry network. Working Paper 2000/04, Sant'Anna School of Advanced Studies, Pisa.

Bonaccorsi, A., Giuri, P., 2001b. The long term evolution of vertically-related industries. International Journal of Industrial Organisation, 19, 1053-1083.

Borgatti, S.P., Everett, M.G., 1997. Network analysis of 2-mode data. Social-Networks 19, 243-269.

Borgatti, S.P., Everett, M.G., 1999a, Models of core/periphery structures, Social Networks, Volume 21, 375-395.

Borgatti, S.P., Everett, M.G., 1999b, Peripheries of cohesive subsets, Social Networks, 21, 397-407.

Bright, C.D., 1978. The Jet Makers. Regence Press of Kansas, Lawrence.

Constant, E.W., 1980. The origin of the turbojet revolution. John Hopkins University Press, Baltimore and London.

Dobson, P.W., Waterson, M., 1997. Countervailing power and consumer prices. Economic Journal 107, 418-430.

Freeman, L.C., 1979. Centrality in social network: I. Conceptual clarification. Social Networks 1, 215-239.

Galbraith, J.K., 1952. American Capitalism. The Concept of Countervailing Power. Basil Blackwell, Oxford.

Hayward, K., 1986. International Collaboration in Civil Aerospace. Frances Pinter Publishers, London.

Hayward, K., 1994. The World Aerospace Industry. Collaboration and Competition. Duckworth & RUSI, London.

Holmstrom, B., Roberts, J., 1998. The Boundaries of the Firm Revisited. Journal of Economic Perspectives 12, 73-94.

Jane's Aero-engines, 1997. Jane's Information Group, Sentinel House.

Jane's All the World Aircraft, 1953-1997. Jane's Information Group, Sentinel House.

LaFrance, V.A., 1979. The impact of buyer concentration - An extension. Review of Economics and Statistics 61, 475-476.

Lustgarten, S.H., 1975. The impact of buyer concentration in manufacturing industries. Review of Economics and Statistics 57, 125-132.

Malerba, F., Nelson, R., Orsenigo, L., Winter, S., 1998. Vertical integration and specialisation in the evolution of the computer industry: towards a “history friendly” model. Paper presented at the 7th Conference of the International Joseph Schumpeter Society, Vienna, June, 13-16.

Miller, R., Sawers, D., 1968. The Technical Development of Modern Aviation. Routledge & Kegan Paul, London.

Mowery, D.C., Rosenberg, N., 1982. The Commercial Aircraft Industry. In: Nelson R. (ed.), Government and Technological Progress. Pergamon Press, New York.

Mowery, D.C., Rosenberg, N., 1989. Technology and the Pursuit of Economic Growth. Cambridge University Press, Cambridge.

Orsenigo, L, Pammolli, F., Riccaboni, M., 2000. Technological change and network dynamics. The case of the bio-pharmaceutical industry. Research Policy, forthcoming.

Orsenigo, L, Pammolli, F., Riccaboni, M., Bonaccorsi, A., Turchetti, G. 1998. The dynamics of knowledge and the evolution of an industry network. Journal of Management and Governance 1 (2) 147-175.

Phillips, A., 1971. Technology and Market Structure. A study of the Aircraft Industry. Heath Lexington Books, Lexington, Massachusetts.

Ravescraft, D.J., 1983. Structure-profit relationships at the line of business and industry level. Review of Economics and Statistics 65, 22-31.

Scherer, F.M., 1980. Industrial market structure and economic performance. Rand McNally, Chicago.

Scherer, F.M., Ross, D., 1990. Industrial Market Structure and Economic Performance. Houghton Mifflin Company, Boston.

Scott, J., 1991. Social Network Analysis. A Handbook. Sage, London.

Sutton, J., 1998. Technology and Industry Structure. MIT Press, Cambridge.

U.S. International Trade Commission, 1998. The Changing Structure of the Global Large Civil Aircraft Industry and Market: Implications for the Competitiveness of the U.S. Industry. Washington D.C.

Vincenti, W.G., 1990. What Engineers Know and How They Know It. Analytical Studies from Aeronautical History. The John Hopkins University Press, London.

von Ungern-Sternberg, T., 1996. Countervailing power revisited. International Journal of Industrial Organisation 14, 507-520.

Wasserman, S., Faust, K., 1995. Social network analysis: methods and applications. Cambridge University Press, Cambridge.

Williamson, O.E., 1985. The Economic Institutions of Capitalism. The Free Press, New York.

Williamson, O.E., 1996. The Mechanisms of Governance. Oxford University Press, New York.

Williamson, O.E., 1999. Strategy Research: Governance and Competence Perspectives, mimeo.