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Firm Networks Dynamics

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Abstract

For this deliverable node CR5 (ENS, Paris), responsible for WP4, has worked in close collaboration with C01 (Rome) and CR3 (Barcelona) focusing on the study of two kind of firm networks: the network of corporate boards and directors and the network of firm ownership in the stock market. The first network is involved in strategic decision making while the second one concerns the capital control structure. We have worked both at the level of characterizing the topological properties of such networks and at the level of developing models of dynamical processes taking place on them. The structure of corporate board network has also an impact on the internal dynamics within firms, a topic which belongs to deliverable D15. For the convenience of the reader the description of this topic in D15 and D16 have some overlap.

Other directions of research developed by node CR5 in deliverable D16 include exploring the effect of network externality in a simple monopolistic market model and the dynamics of continuous opinion propagation in networks of economic agents.

- **Introduction**

Graph Theory has provided during the last decades an excellent characterization of random graphs (Bollobàs '85). Issues of centrality (which individuals are best connected to others or have most influence) and connectivity (whether and how individuals are connected to one another through the network) have also been addressed in the social sciences (for a general theory of social networks see [Friedkin 2001], for an example see the study of the network of ties of the De Medici family, [Padgett '93]).
However, real socio-economical networks are often poorly described by means of random graphs and many dynamical processes display on realistic graphs a behavior dramatically different than on random graphs (ad example the spread of viruses and the Ising model). Moreover, the process of organization of human activities in global world-wide interwoven structures, results in networks the size of which goes beyond the descriptive power of traditional network analysis tools. For instance, the network of cross-country capital control includes some 10^5 firms. Given the enormous impact of firm networks on the welfare of individuals and institutions (see ad ex. the failure cascade in the East Asia in 1997, Stiglizt 2002), it is crucial to address the issues of efficiency and robustness of such systems. From a policy making point of view, we may also want to know whether it is possible to guide somehow the evolution of such systems in order to meet some requirements of safety or social utility.

Node CR5 (ENS), responsible for WP4, has worked in close collaboration with C01 (Rome) and CR3 (Barcelona) in order to produce deliverable D16. Such collaboration has focussed on the study of two firm networks with a major impact: the network of corporate boards and directors and the network of firm ownership in the stock market. The first network is involved in strategic decision making while the second one concerns the capital control structure. We have worked both at the level of characterizing the topological properties of such networks and at the level of developing models of dynamical processes taking place on them. We explain in the following what contribution this study has brought to the deliverables.

In the context of choices in market networks, some of us have also studied a model of a simple market with a single homogeneous product and a single seller (the monopoly case) exploring the effect localized network externality.

Another direction of study taken by CR5 team concerns the dynamics of continuous opinion propagation in networks of socio-economic agent. This research line relies on a collaboration with a CEMAGREF team engaged in the sociology of agricultural practices (CEMAGREF is a French national research institution for management of agricultural and environmental resources.

- **Networks of interlocked firm boards of directors**

The boards of directors of the largest corporations of a country form a highly interwoven *bipartite network* (A link represents the fact that a director serves on a board. When a director serves on several boards there is a so called "*interlock*"). After recent cases of bankruptcy in the western countries (Enron, Vivendi, Parmalat), the role of boards is widely under discussion in the public opinion. It is clear that two issues need to be addressed:

1. on one side we need to provide a characterization of the topological properties of such networks and to compare such properties across time and countries.
2. on the other side we need to know how the structure of these networks influences the decision making process in which directors are involved.

Davis and collaborators have shown (Davis et al. 2003) that the director network and the board network of the Fortune 1000 corporations has Small World properties in the sense of Watts and Strogatz (Watts and Strogatz 1998). Newman, Watts and Strogatz (Newman et al. 2001) have applied on the same data set a generalized random graph model, reproducing very accurately the degree distribution of the director network, but failing in predicting the degree distribution of the board network. Newman and Park (2003) have recently argued that the presence of groups or communities in a social network is able to produce alone both assortativity and clustering. However such model explains only about 40% of the observed assortativity in the Fortune 1000 network and this means that the sociological mechanisms which are at work in shaping the topology of the network can not be neglected.

Battiston (CR5) and Catanzaro (CR3) (Battiston and Catanzaro 2004) have performed an extensive and comparative analysis of both a novel data set (the boards and directors of the companies in the Italian Stock Market) and the data set previously analyzed by Davis and Newman.

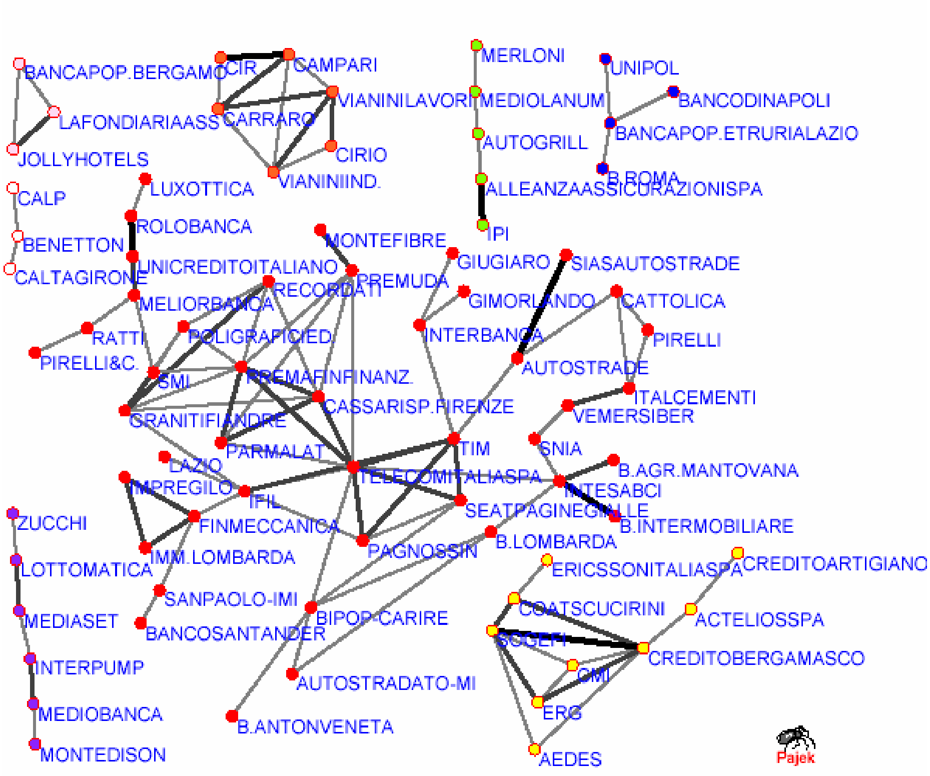

Figure 1. Boards of directors of firms in the Italian Stock Market: the network of boards that share two (gray links) or more (black links) directors.

They show that several statistical properties are common to the different data sets despite the fact that they refer to different years and countries. Moreover some of these properties they deviate from the properties that the network would have if links were drawn at random in a network with the same constraints (number of board, number of directors, number of directors in each boards, number of boards per director). These facts suggest that some universal formation mechanism is at work for this kind of networks, a mechanism which is not captured in a satisfactory way by the existent models of social network formation.

- **Interlock structure and Spread of Decisions**

Most models about opinion dynamics are based on binary choices that social actors update as a result of social influence, often with update mechanisms that are formally equivalent to variants of the Ising model. In such class of models the topology is known to play a crucial role (Leone et al. 2002).

In this context, unlike previous works, CR5 has worked on models in which the opinion dynamics takes place on an empirical heterogeneous network organized in interconnected groups. In [5, 6] CR5 have studied a decision making dynamics taking place on the network of corporate directors, both at a single firm level and at a firm network level. Several social sciences approaches on decision making assume that decisions are binary and that agents influence each other to an extent proportional to the strength of their professional relationship. CR5 contribution to the field consists in pushing these assumptions to their full consequences and to choose the "right" quantities to study. We distinguish two cases whether boards make decisions independently or not from other boards and we assume an Ising-like dynamics on the variables representing directors' opinions. We are then in a position to address two fundamental questions:

1. can a minority of well connected directors (a "lobby") drive the decision of the majority of a board and can we predict the impact of the minority based on its topological structure?
2. under which conditions a large majority of boards making the same decision can emerge in the network?

Answering to the first question is part of another deliverable D15 (Modelling interaction and dynamics within firms). Results are published in (Battiston et al. 2003 [5]). The prominence of questions such the ones above is witnessed by the fact that the article has attracted the interest of the general public press [8].

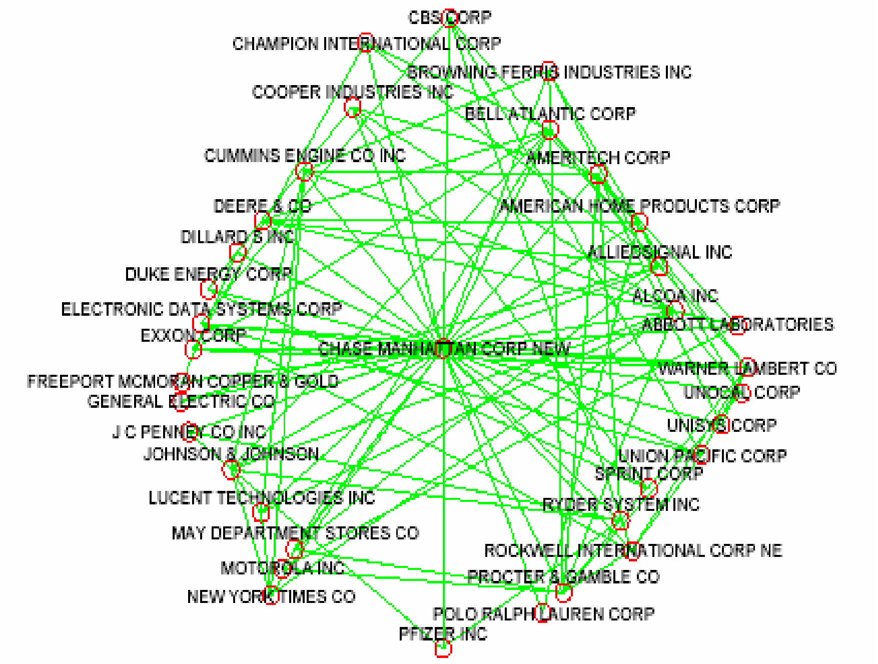

Figure 2. The network of the boards of directors one degree of separation away from the board of Chase Manhattan Bank. A link represents one or more directors in common.

This work also contribute to D7 (Centrality and Groups in Social Networks) because it introduces a new notion of centrality of actors related to the role of the lobby.

As for the second question, it is quite intuitive to think that the interlock can be responsible for the diffusion of decisions through boards. But how do we measure and predict this effect?

We design a model [6] with two scenarios: in the first one the information about other boards' decisions only affects the opinions of directors who serve on multiple boards when they go from a board meeting to another one. In the second scenario such information is taken into account by all directors during the whole board meeting. The decision making process within a board is modelled as in the previous work [5]. Agents feel a field which takes into account the opinions of other agents and (only in the second scenario) the decisions taken in connected boards.

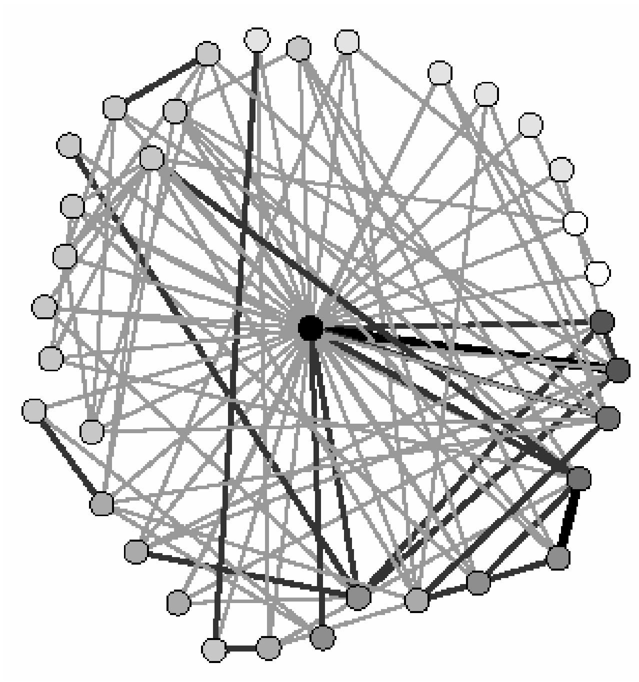

Figure 3. The model introduced in [6] simulates a propagation of decisions across the network of boards of directors. The color of the nodes represents the probability that a board adopt the same decision as Chase Manhattan (in the center).

It turns out that only in the second scenario there is an avalanche of boards making the same decision. The most interesting point here is maybe the counterintuitive result that interlock alone does not produce any avalanche of decisions. One has to suppose some form of information transfer in order to have an avalanche. This is neither a trivial nor an expected result. (Battiston et al. 2003b [6]).

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- **Continuous opinion dynamics**

A model of opinion formation that cannot be described in terms of an Ising-like dynamics is the model introduced by some of us (Weisbuch) and our collaborators at CEMAGREF (Deffuant et al. 2000). This new consensus model is based on continuous opinions and bounded confidence. The motivations of this model stems from situations often encountered in economic and social science: for instance in the case of technological changes, firms have to compare the utility of a new technology with respect to the old one. See Weisbuch (2004) for a bibliography on this topics). In the model of Deffuant et al., a tolerance threshold d is defined, such that agents whose opinion differ more than d cannot interact. Several variants of the model have been proposed in (Weisbuch et al. 2002) and in (Deffuant et al. 2002). In these models, the only restriction for interaction is the threshold condition and interactions among any pair of agents can occur.

The attractor of the dynamics consists of a number of clusters in the opinion distribution. In each cluster agents have the same value $x \in [0\ 1]$ of the opinion. The number of clusters increases discontinuously when the tolerance threshold is decreased.

A main issue in this class of models is to understand whether the properties observed in the all-to-all interaction case changes when the same dynamics takes place on a scale-free network. We presented at the Mid-Term COSIN conference in Rome (9/2003) the results of simulations made on scale-free networks [35]. It turns out that the network topology does not induce any dramatic change in the behavior of these models as compared to the well mixed case:

- One does observe clustering effects, and the number of observed main clusters does not largely differ for what is observed for equivalent tolerance thresholds in the well mixed case.
- Well connected nodes are influenced by other nodes and are themselves influential.
- Most of them belong to the big cluster(s) after the clustering process.
- Larger connectivity values bring scale-free network dynamic behaviour closer to the well mixed case.

- **Network externality in a monopolist market**

We explore the effects of localised externality in the simplest market model: the discrete choice model with a single homogeneous product and a single seller (the monopoly case). The market is viewed as a complex interactive system with a communication network between entities. We use an ACE (Agent based Computational Economics) approach to investigate corresponding market mechanisms and underline in what way the knowledge of generic properties of complex adaptive system dynamics can enhance our perception of the market mechanism in the numerous cases where individual decisions are inter-related. More specifically, we discuss analogies between simulated market mechanisms and classical phenomena in the physics of disordered systems such as phase transition, symmetry breaking, avalanches and long range dependence. Various network structures are taken into account: as regular network (lattices) and random networks represent two limiting cases of localized interaction structures, the so-called small-world networks are an intermediate form between these two extremes.

- **Capital control networks**

In collaboration with C01(Rome), we apply the statistical physics approach to the study of the structure of capital ownership in stock markets and we unveil some unexpected properties. This is a contribution to deliverable D16 but as we will see below it also contributes to deliverable D7.

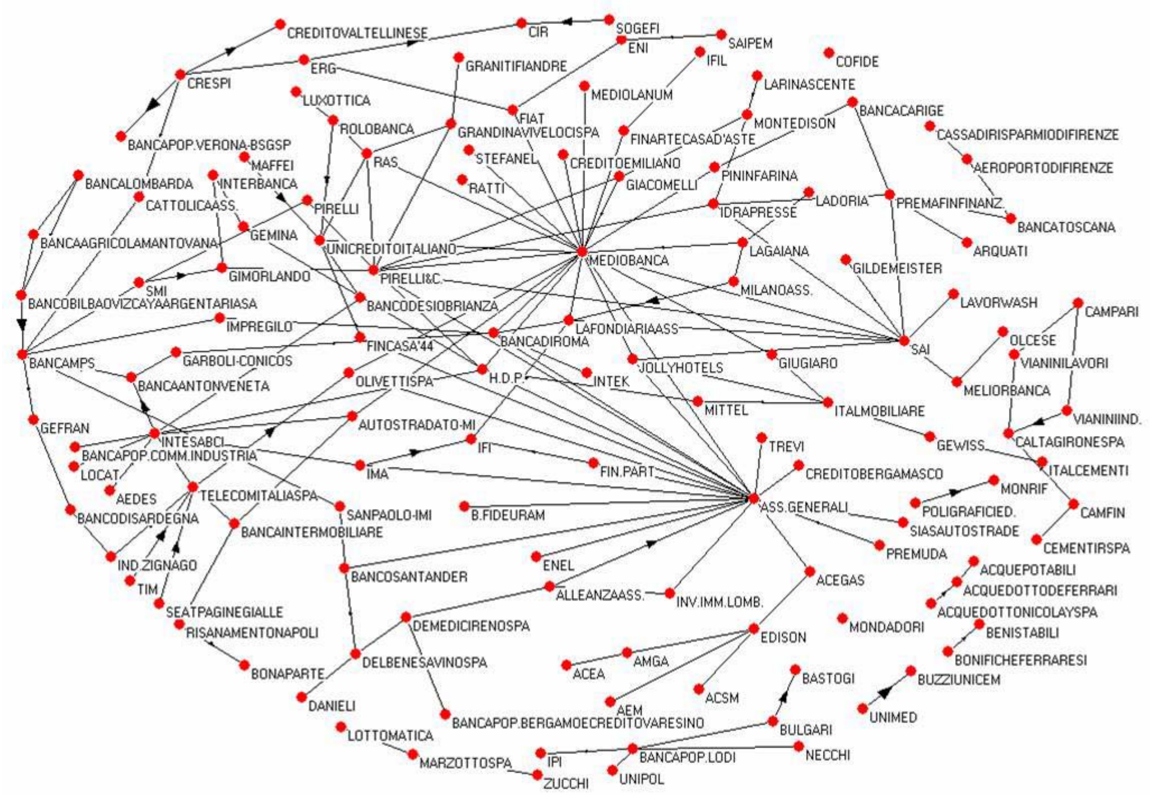

Figure 4 The Network of Stock participation in the Italian Stock Market. Only quoted companies are represented. A link represents the fact that a company holds shares of another company.

Despite the obvious importance in economics of issues like the robustness of such networks against failure avalanches, surprisingly, systematic studies of the topological properties of such networks had not been previously carried out. Jackson has introduced several model of formation of socio-economic networks (see for instance [18]), addressing the issue of the stability of such networks based on a game theoretical approach. No real networks are analyzed though. The group of R. Mantegna (see for instance [22]) and the group of J. Kertsz (see for instance [26]) have studied the network produced by the correlation among price return time series in the stock market, revealing interesting relationships between the topology of such network and phases of the market (ad example during crashes correlation increases and the network shrinks).

We focus instead the network of capital control. An interesting related work is the one by Kogut and Walker in 1999 [20] But the socio-economic literature seems still quite poor in this direction. The central question we address is whether it is possible to classify stock markets based on structural properties of the capital control network. We find that the portfolio diversification and the invested volume display power law distributions with different exponents across data sets. Moreover the portfolio diversification scales as a power-law function of the invested volume. These findings seem in contradiction with classical portfolio theory and suggest some universal properties of stock markets. In other words one can introduce a simple mechanism of network formation in which investors, as observed empirically, diversify their portfolio to an extent that depends on the wealth they are endowed with. Assuming the empirical distribution of invested wealth among the agents, one recovers quite neatly the scale free distribution for the portfolio diversification. While this is not a surprising result because the portfolio diversification and the invested volume are empirically found to be correlated variables, the model offers a novel mechanism of formation of a scale free network which does not require growth or preferential attachment as in most current models of scale free networks. Such results contribute to D16 in that they concern a firm-firm link formation.

Weighted networks are still rarely investigated. We introduce two indices analogous to in-degree and out-degree for graphs, quantities that take into account the relative importance of shareholders. It is important to stress that without those quantities one simply cannot answer the following questions:

1. how small is the subset of "investors" that controls the major part of a market.

2. how such "super-investors" share out the market among themselves (whether each one controls different companies or if instead they control the same companies).

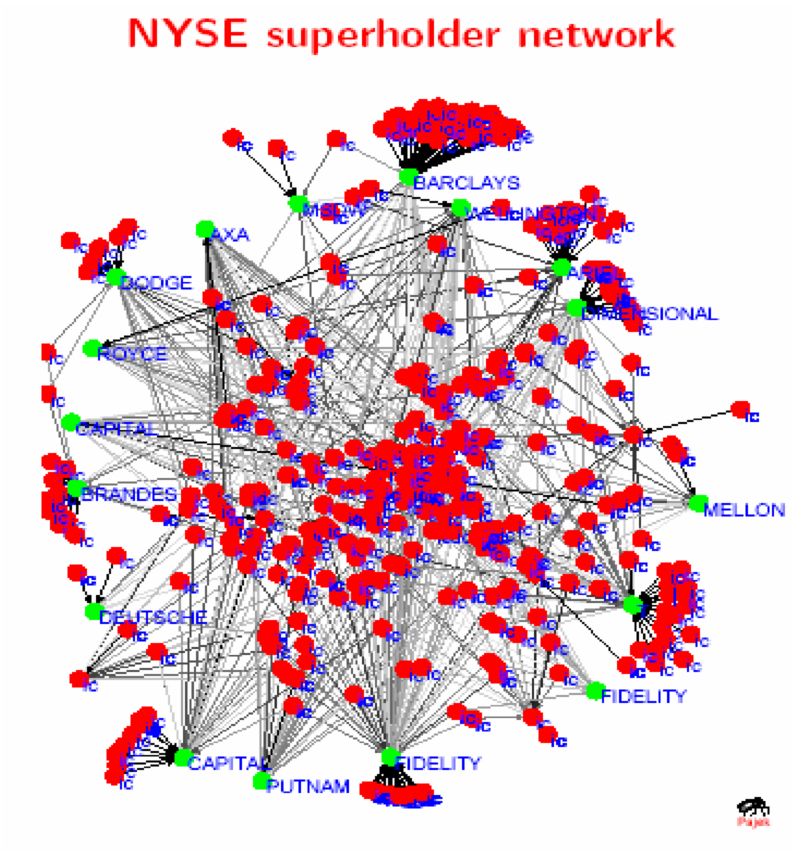

Figure 5. The network of the top investors (green) in the New York Stock Exchange Market and the stocks (in red) they control.

The results are quite neat: the Italian market splits up in groups of interest, while the US markets do not. Our indices allow to measure the centrality of actors in a way specific to economical networks, thus contributing not only to D16 but also to D7). The method we introduce provides also a tool to measure the concentration of power in a market and to extract its backbone. It contribute to D7 also in the sense that allow to detect socioeconomical "groups". The idea of defining a "participation index" is certainly not new in economics (for instance to measure the effective number of firms who share a market, the "Herrfindale index"), but the idea of using this kind of index for both in-degree and out degree in order to extract the backbone of the network is completely new at our knowledge and stems genuinely from thinking at the market in terms of a network.

With respect to the now traditional topic of scaling laws in complex networks [25], the important lesson we learn from these results is also that under the veil of common scaling laws for the connectivity distribution, deep structural differences can hide in the weights of financial networks.

- **Scientific Production**

Overall this deliverable includes the following publications:

[2] Battiston S., THE INNER STRUCTURE OF CAPITAL CONTROL NETWORKS, to appear on *Physica A* (2004).

[4] Battiston S. and Catanzaro M., Statistical properties of board and director networks, to appear on *EPJB* (2004).

- Battiston, S., Weisbuch G., Bonabeau, E., DECISION SPREAD IN THE CORPORATE BOARD NETWORK, *Adv.Compl.Syst.*, Vol 6, No. 4. (2003).

- Battiston, S., Caldarelli G., Garlaschelli D., THE HIDDEN TOPOLOGY OF SHAREHOLDING NETWORKS, submitted (2004).

- Garlaschelli D., Battiston S., Castri M., Servedio V.D.P., Caldarelli G., THE SCALE FREE NATURE OF MARKET INVESTMENT NETWORK, 2003, submitted, cond-mat/0310503

-Caldarelli G., Battiston S., Garlaschelli D., Catanzaro M., EMERGENCE OF COMPLEXITY IN FINANCIAL NETWORKS, to appear in *Lecture Notes in Physics*, special volume on "Complex Networks", Springer (2003).

- Phan D., Pajot S. Nadal J.P., *Ninth annual meeting of the Society of Computational Economics, University of Washington, Seattle, USA*, 2003, http://digemer.enst-bretagne.fr/ phan/papers/ppn2003.pdf

- Weisbuch, BOUNDED CONFIDENCE AND SOCIAL NETWORKS, to appear in the proccedings of Roma Cosin Conference, *EPJB* (2004).

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