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COSIN Working Package 4: Social Networks
Deliverable D16: Firm Networks Dynamics

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I. OVERVIEW OF THE DELIVERABLE

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 kinds of firm networks: the **network of corporate boards and directors** and the **network of firm ownership** in the stock market during years during the first two years of the contract(2003-2004). 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 eralier 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. . We have been able more recently (2005) to study avalanches of failures and bankrupcies in **firms credit and production networks.**

A. Networks of interlocked firm boards of directors

The boards and the 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 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 [10]) 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 [23]) 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 [4]) 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. They show that several statistical properties are common to the different data sets despite the fact that they refer to different years and countries. 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.

B. Interlock structure and Spread of Decisions

Most models about opinion dynamics are based on binary opinions that social actors update as a result of social influence, often with update mechanism that are formally equivalent to an **Ising model**, in which the topology is known to play a crucial role (see D15).

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). This result is published in (Battiston et al. 2003 [5]). The prominence of questions such the one we have addressed here is witnessed by the fact that the article has attracted the interest of the **general public press** [2].

This work also contribute to D7 (Centrality and Groups in) 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 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. 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.

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. One **has** to suppose some form of information transfer in order to have an avalanche and this is not a trivial nor an expected result. (Battiston et al. 2003b [6]).

C. Continuous opinion dynamics

A model of opinion formation that cannot be described in terms of an Ising-like dynamics is the model recently introduced by Deffuant et al. (2000). This new consensus model is based on **continuous opinions and bounded confidence**. The motivations of this model stem 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 $x \in [0 \quad 1]$ 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 [34]. 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.

D. 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 localised interaction structures, the so-called small-world networks are an intermediate form between these two extremes. (Phan et al. 2003)

E. 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.

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 [17]), addressing the issue of the stability of such networks based on a game theoretical approach. No real networks are analyzed, though. R.

Mantegna [21] and the group of J. Kertsz [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 [19]. 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 recover quite neatly the scale free distribution for the 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 an firm-firm link formation.

Weighted networks are still rarely investigated (Barrat et al. 2003). 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).

The results are quite neat: the italian market splits up in groups of interest, while the US market 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 socio-economical "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 [24], 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. The results of these two chapters are reported in (Garlaschelli et al. 2003 [16], Battiston et al. 2003c [7], Battiston 2003)

F. Credit networks

Due to the fact that firms usually pay their suppliers 1-3 months after the delivery, relationships of supply-customer among firms result *de facto* also in credit relationships. In the '80s economists have re-discovered the role of financial factors in business fluctuations (see for instance Greenwald and Stiglitz, 1993). Recently, the multi-agent models of Delli Gatti et al. have shown that heterogeneity (in terms of degree of financial fragility) of firms plays a crucial role in the evolution over time of aggregate variables such as production and employment. They find that financial indicators, like equity ratio, are good predictors of financial crises.

However, another prominent issue to investigate is how financial fragility is affected by the structure of the firm-firm credit network. Stiglitz and Greenwald have suggested in particular credit networks as a prominent source of economic instability [Greenwald and Stiglitz, 1993]. However no formal model including cascades on networks has been studied in the literature. Per Bak et al. have shown in a simple model inspired to sand-pile dynamics that in supply networks idiosyncratic and uncorrelated shocks can result in large oscillations of the total outcome of an economy. But,overall credit networks have been poorly studied so far, both from an empirical and a theoretical point of view as the importance of investigating the role of networks in economic processes has gained visibility only in recent years. In the last twenty years the sand-pile model has been suggested as a prototype model for many natural systems that respond to external perturbations by a hierarchy of avalanche events with power-law-distributed size. Avalanches of failures of firms and avalanches of link rewiring present several similarities with the sand-pile metaphor and other models of cascade events that have been recently re-investigated in the physics community in the context of Complex Networks.

To investigate the role of credit networks we have developed a simple model of failure propagation on a network of firms linked by supply-customer relationships. In this model failure to delivery is not assigned exogenously with a fix probability but is a result of the dynamics. Also, failure to pay can occur. From a physical point of view it turns out that the dynamics can be described as multiplicative stochastic process with repulsive barrier and interaction. We are able to reproduce some stylized fact of firm demography as done by previous models. Moreover we are able to produce genuine endogenous avalanches of failures, that are due to the local supply-credit interaction among firms and appear clustered in time. We find that avalanches of failures are caused by the "inertial cost", in other words the inability of firms to adapt instantly their costs to the demand. Inertial cost has to do with cost of premises and labour. The latter can hardly be adjusted at a fast pace without inducing social cost for the whole economy.

Further investigation is needed to fully understand how bankruptcies avalanches and stylized facts depend on the parameters of the model. However, the sudden drops in the total outcome of the economy that emerge spontaneously could suggest a possible endogenous mechanism for business cycles.

G. Production networks

We were only able to start working on a model of production networks among firms from 2004: as often, a simplification (forget about prices!) opened the door that we could not open in our previous efforts. Production networks are built from production interactions among firms: what is produced by one firm is used as inputs for their own production by other firms. The economy can be viewed as a production network where production flows from natural resources to consumer goods.

Such production networks can be viewed as generalised supply chains: one can then be interested in applications such as scheduling and robustness against perturbations, information flow, decision structures...

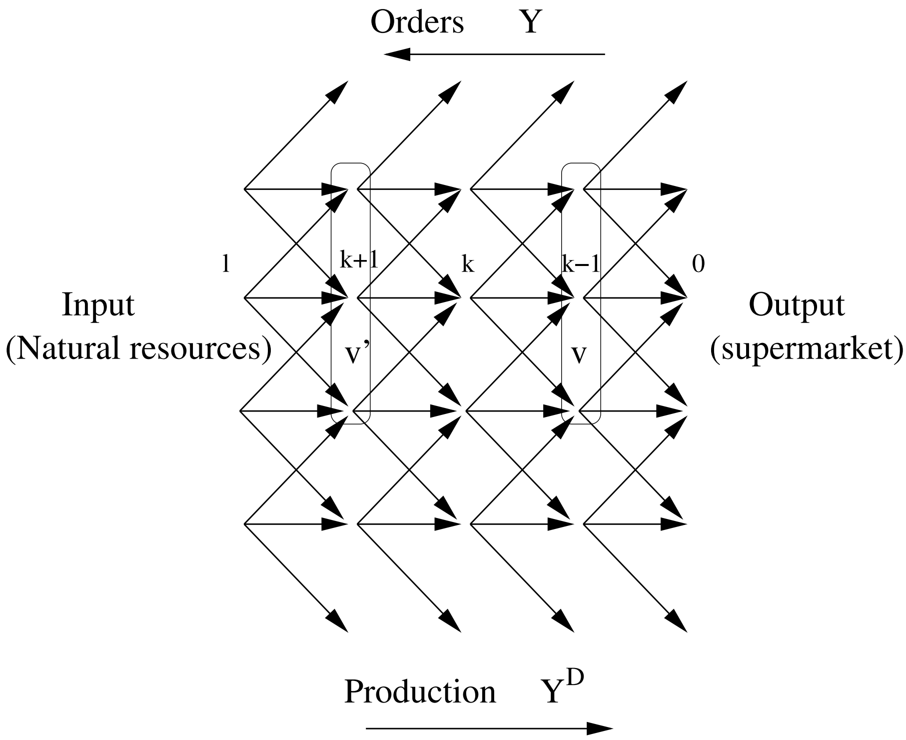

FIG. 1: Firms are located at the nodes of the lattice. Production (Y^D) flows from the resource input layer ($k = l$) to the output layer ($k = 0$), orders (Y) flow backward.

We worked on a class of simple models of production networks under noisy environment: in our model, noise is due to local production failures (random shocks). A similar model considerd by Stefano Battiston concerns credit networks. As pointed out by Stiglitz, and then developped by D. Delli Gatti, C. Di Guilmi, E. Gaffeo, G. Giulioni, M. Gallegati and A. Palestrini, firms are also connected via credit relations. Firms not only borrow from banks but from each other. Failures to re-imburse debts in these credit netwoks was studied in Delli Gatti etal and later by Stefano Battiston. (We borrowed from Delli Gatti etal the idea to forget about price dynamics to simplify modeling). Delli Gatti etal networks is a simple starlike structure, with a central bank as the center of the star. We studied lattice-based networks.

We observed, as expected, scale free distributions of production and wealth among firms.

More unexpected was the spatial organisation of firms in active or depressed regions as observed in geographical economics. As contrast to standard spatial analysis of economists, as described e.g. in Fujita and Thisse, "Economics of Agglomeration Cities, Indutrial Location, and Regional Growth" (2002, Cambridge University Press) the strong localisation that we here report is due to the local autocatalytic growth in the presence of noise (reaction-diffusion equations). The mechanisms have some common properties with directed percolation, polymers in random media ... which models were exactly solved by physicists (see e.g. KPZ).

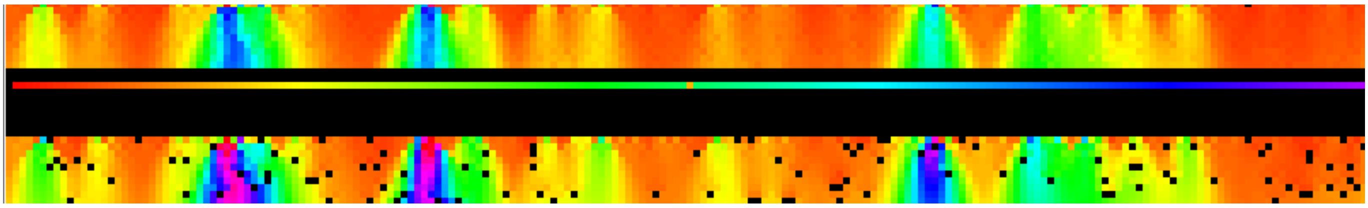

FIG. 2: Patterns of wealth(upper pattern) and production (lower pattern) for a 200x10 lattice. For both patterns the output layer is the last one above. The intermediate line is the colour code, with minimal amplitude at the extreme left. We observe alternance of highly productive regions (in pink, blue and green colour), with less active regions (in red). Local production failures represented by black dots are randomly distributed across the production pattern. Only one bankrupted firm is observed on the wealth pattern.

One important finding of the model is that active regions are metastable mesoscopic entities with scale-free distributions of production and wealth.

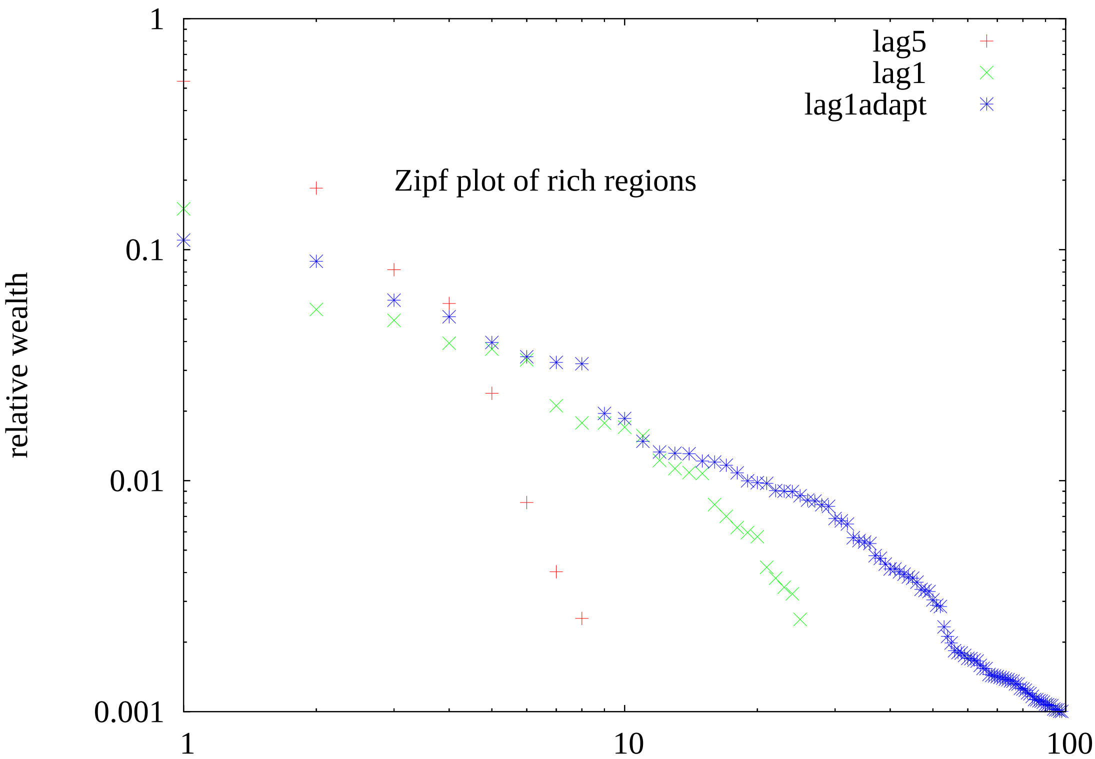

FIG. 3: Zipf plot of wealth of the most active regions for the standard and adaptive firms models. The vertical axis display the production relative to the total production. The red '+' correspond to the standard model with time lag = 5, green 'x' to time lag = 1, and blue '*' to the adaptive firms model with time lag = 1.

II. PUBLICATIONS WITHIN THIS DELIVERABLE

Overall this deliverable includes the following publications:

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[3] [Battiston 2004] Battiston S., The inner structure of capital control networks, 2003, to appear on Physica A.

[4] [Battiston and Catanzaro 2003] Battiston S. and Catanzaro M., Statistical properties of board and director networks, 2003, submitted.

[6] [Battiston et al. 2003 b] Battiston, S., Weisbuch G., Bonabeau, E., Decision spread in the corporate board network, 2003, to appear on Adv.Compl.Syst. 1 2003

[7] [Battiston et al. 2003 c] "Battiston, S., Caldarelli G., Garlaschelli D., The hidden topology of shareholding networks, 2003, submitted.

[16] [Garlaschelli et al. 2003a] 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 v1

[29] [Phan et al. 2003] Phan D., Pajot S. Nadal J.P., "The Monopolist's Market with Discrete Choices and Network Externality Revisited: Small-Worlds, Phase Transition and Avalanches in an ACE Framework", Ninth annual meeting of the Society of Computational Economics, University of Washington, Seattle, USA, July 11 - 13, 2003, http://digemer.enst-bretagne.fr/ phan/papers/ppn2003.pdf

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