FIRST YEAR PROGRESS REPORT

EU FET OPEN PROJECT FOC
255987

forecasting financial crises

Deliverable D2.1

"Report on Activity in WP2 - Agent based modeling"

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Objectives

This WP covers the theoretical effort of the project, dealing with a wide range of topics related to financial networks. From a methodological point of view, the theoretical work lies at the intersection of the two growing fields of agent based modelling and of social network theory, and it tries to pursue a stronger interaction between the two approaches, taking advantage of the different disciplinary backgrounds of the researchers involved. The tasks involved in this WP are the following:

- T2.1 Agent-based models of short term financial network
- T2.2 Agent-based models of mid/long-term financial networks
- T2.3 Onset of instability and Self-Organised Criticality
- T2.4 Immunization strategies

Progress Overview

The only task active during the first year of the projects is **T2.1**. Activities carried out under this task include both the development of a model of the interbank market (T2.1.1) and the development of a model for credit supply to the real sector (T2.1.2). Regarding the first activity, we aim to verify the following hypothesis: when banks are heterogeneous, an increasing connectivity of the interbank network implies a more severe trade-off between the stabilizing effect of risk diversification and the destabilizing effect of bankruptcy cascades. Regarding the second activity, we aim to bridge a gap in the existing interbank network models by developing a model for the supply of credit to the real sector, in order to asses the effects over the interbank market of real shocks such as a wave of firms' defaults associated with a recession.
We report also preliminary results for tasks **T2.2**, **T2.3** and **T2.4**.

T2.1 Models of Short-term Financial Networks (Planned duration Month 1-24)

T2.1.1 Interbank market

The goal of this activity is to explore whether adaptive learning processes at the level of the individual bank can generate trading strategies that reproduce certain stylized facts of the interbank market. Furthermore we would like to explore the robustness of these strategies at times of tight liquidity constrains such as the recent credit crisis. We are particularly interested in the role of bank heterogeneity in influencing inter-bank lending patterns during times of crisis.

To this end, the City research unit has developed a preliminary model of the interbank market. This is intended to act as a basis upon which we will build a more feature-rich representation. At the moment, the model allows borrowers to evolve probability distributions over bidding rates when asking to borrow. A simple description of the algorithm follows.
Initialize a set of banks. Banks are allowed to borrow at a finite set of rates and each bank assigns a numerical attraction to each rate. Initially all attractions are uniform. Then for all times.

1. Draw liquidity fluctuations to assign banks to a borrowing or lending set. Liquidity fluctuations are (in the current version) picked such that there is always a surplus of liquidity supply. All liquidity fluctuations are equal for each bank.
2. Banks in the borrowing set pick a bidding rate as a function of its attraction. Functions of form include logit and power laws.
3. The order of lenders is shuffled and then they take turns picking the highest biding borrower that hasn't already traded.
4. Borrowers calculate their payoff as a decreasing function of the rate.
5. Borrowers update their attractions to each rate, including ones not used for the current trade using reinforcement learning.

The system is characterized by the evolution of the rate attractions and as expected evolves to a state where borrowers bid at the lowest allowed rate. Our short terms goals come from relaxing certain of the assumptions of the base model and iteratively layering complexity. The next step will be to explore markets with liquidity deficit, so that borrowers with low bids will have to resort to borrowing from a central bank at a higher rate. Following this, we shall (i) similarly model learning behaviour on the part of lenders, (ii) allow for the aggregate market liquidity to itself randomly vary between surplus and deficit. All banks will then have two separate mappings from rate space to attraction space separately when borrowing and when lending. Beyond this, we shall extend the base model to incorporate greater complexity in the decision-making process.

T2.1.2 Banks-Firms credit market

As stated in the project, in order to bridge a gap in the literature between interbank' dynamics and banks-firms dynamics, we have developed a model where the supply of loans from the banks is matched with a demand of loans originating from financially constrained firms facing random market-price shocks, following the approach proposed by Delli Gatti et al. (2010). These analyses are in two working paper done by Luca Riccetti, Alberto Russo and Mauro Gallegati, one of which will be presented at REPLHA (Rethinking Economic Policies in a Landscape of Heterogeneous Agents) International Conference, that will be held on October 13-15, 2011 at Catholic University, Milan (Italy).

In the first working paper, entitled "Leveraged network-based financial accelerator", the authors introduce the Dynamic Trade-Off theory (Flannery and Rangan, 2006) to model firms' capital structure. This theory hypothesizes that firms have a target leverage. It implies that a growing firm will balance the increasing capital with increasing debt exposure, thus creating in good periods the basis for the subsequent crisis. Besides confirming some results already found in Delli Gatti et al. (2010), such as the emergent right-skew distribution of firms' and banks' size even if all firms start from the same conditions, or the possibility that an idiosyncratic shock creates a systemic crisis, the most important result is that: if leverage increases the economy is riskier with a higher volatility of aggregate production and a strong increase of firms and banks' defaults. Moreover, the pro-cyclicality of credit clearly emerges. Indeed, during the expansionary phase of the cycle, gains make firms accumulate capital and the decrease of firm defaults reduces bad debt; this allows firms to borrow more both because they are more capitalized and because banks are financially sounder and lend at lower interest rates. The increased leverage boosts firms' growth until the system reaches a critical point of financial fragility and the cycle is reversed through an increase of defaults. This feature is evident in the following figure that shows the cross-correlation between leverage and firm net worth: when firm net worth increases the leverage increases (left side of the figure: positive correlation between net worth and subsequent leverage); than, after a while, the increased leveraged implies a decreases of firm net worth (right side: negative correlation between leverage and lagged net worth).

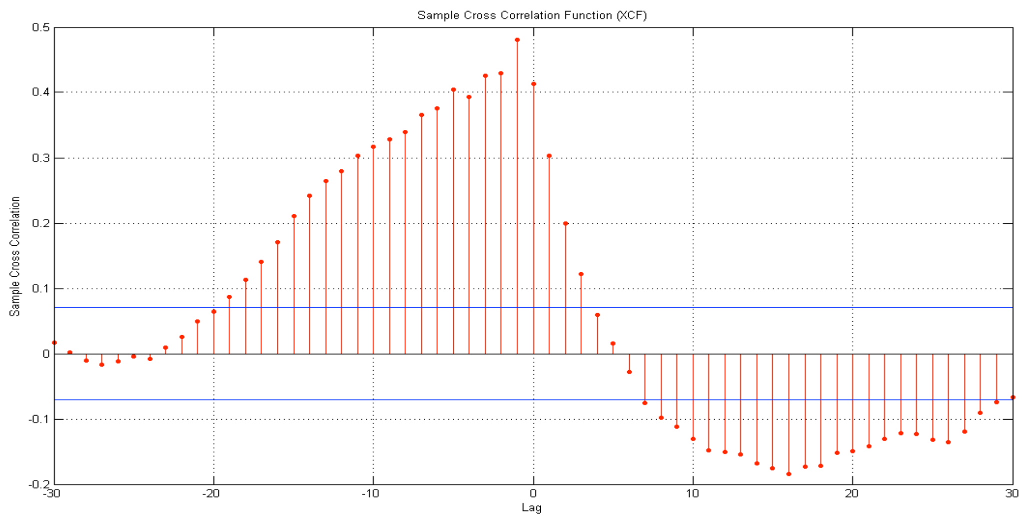


Figure 1. Sample cross correlation function for varying level of the lag.

The authors also insert the recovery rate (RR) or loss given default rate (LGDR) in the framework, finding that the amount of losses that banks suffer in case of borrowers' default is a strongly significant determinant of the number of bank defaults. The policy maker should develop bankruptcy regulation in order to improve the stability of banks and, consequently, of the overall economic system.

In the second working paper, entitled "Bank Credit, Stock Market Dynamics and the Network-based Financial Accelerator", the authors add the presence of the financial market to the model of Delli Gatti et al. (2010). Stock market valuations influence the distance-to-default used to evaluate firms' financial soundness and, thus, to set the interest rates charged by banks to firms. The introduction of the stock market enriches the positive feedback mechanism of the Network-Based Financial Accelerator of Delli Gatti et al. (2010) with a further accelerator mechanism, that the authors call stock market accelerator. Indeed, a firm with lower profits has a decreasing capitalization on the stock market; thus the distance to default reduces and banks ask a higher interest rate. The increased interest rate reduces the firm profit, amplifying the standard financial accelerator.

In this framework, the authors find a number of preliminary results (interesting for the policy makers too). The most important are:

1. the stock market amplifies shocks on the real side of the economy. This effect is stronger when the stock market multipliers (used to evaluate firms equity values) are high, because they enlarges the stock market financial accelerator;
2. a shock on the financial market may be dangerous for the real economy. An increase in the propensity of investing on the stock market (as a symptom of a mounting financial market bubble), creates a period of recession: a highly volatile stock market reduces the distance to default of the firms, increasing the interest rates, thus making firms financially weaker, the rate of bankruptcy gets higher and also firm defaults tend to cluster more;
3. the restrictive monetary policy creates a recession phase, but it also creates a higher number of bank failures when the banking system is poorly capitalized. Thus, a Central Banks should previously check if the banking system is well capitalized, to avoid cases such as the financial crises started in 2007 after a monetary restriction phase.
4. the stock market multiplier could be affected by the interest rate level and this effect partially counteracts the effect of the monetary policy on the real economy. Central Banks should consider this when deciding monetary policy changes.

In the next year the authors will also try to extend the model in order to incorporate an interbank market conceived along the lines described in section T2.1.1.

T2.2 Models of Mid-term Financial Networks (Planned duration Month 24-42)

The main goal under this task is to extend the results of previous works to more complex market settings. In particular, we wish to verify if the destabilizing effects of interdependence and trend reinforcement may be exacerbated by allowing for trading in derivative credit contracts. In order to do so, we must implement in the first place a dynamic version of the static network model of Eisenberg and Noe (2001), which can be later extended to include mutual exposure on derivative contracts. In particular, we are interested in describing the trajectories of the system by means of stochastic differential equations, which may provide a useful theoretical tool for forecasting both agent-based simulated and real world data. A complementary line of research regards the description of a credit market at equilibrium as a statistical ensemble. Building upon such description, the tools of statistical mechanics can potentially provide valuable means for an empirical analysis of real credit markets. The results provided below are still preliminary, and they will need to be assessed and developed further in the next future.

T2.2.1 Risk sharing and distress propagation

Under this activity, the study of the interbank market is pursued in terms of network analysis, with the aim to show that an increasing connectivity of the interbank network implies a more severe trade-off between the stabilization effect of risk diversification and the higher systemic risk associated with potential bankruptcy cascades triggered by stronger connectivity. The most significant papers written or revised and submitted to various journals are:

- "Liaisons Dangereuses: Increasing Connectivity, Risk Sharing, and Systemic Risk", Battiston, S., Delli Gatti, D., Gallegati, M., Greenwald, B. C. N. and Stiglitz, J. E.; submitted to the special issue of Journal of Economic Dynamics and Control;
- "Default Cascades: When Does Risk Diversification Increase Stability?", Battiston, S., Delli Gatti, D., Gallegati, M., Greenwald, B. C. N. and Stiglitz, J. E.; submitted to the Journal of Financial Stability.

Both these analyses investigate the role of different network structures and their possible evolution in time. A first step of these works is to find a law of motion for the debt/equity ratio of agents, considering the debt/equity ratio (that is an alternative to the leverage) as the measure that represents the financial robustness of a firm or bank. Then, these laws of motion, that are based on a stochastic differential equation (SDE) framework, are a description of the change over time of the financial robustness. A second step is to bridge such laws of motion with the probability of default, measured by concept similar to the distance to default. In such framework it is possible to analytically compute the probability of default in terms of a first-passage-time problem.

In the paper "Liaisons Dangereuses: Increasing Connectivity, Risk Sharing, and Systemic Risk", the authors improve over current works, which are only based on risk sharing (such as in Allen and Gale, 2001), by adding the financial accelerator concept to the network interdependence mechanism. The financial accelerator is a positive feedback mechanism that can enlarge the effect of the initial shock. It is activated in various ways. The first one is an agent hit by a shock due to a loss of market value of some securities in her portfolio. If such shock is large enough, so that some of her creditors claim their funds back, the agent is forced to liquidate at least part of her portfolio to reimburse debt (fire-selling). If the securities are sold at a low price, the asset side of the balance sheet decreases impairing capital on the liability side, and the agent's fragility - i.e. leverage - goes up. A second scenario is the one in which, when borrowers' financial conditions worsen, her creditors makes credit conditions harsher in the next period, asking a higher risk premium.

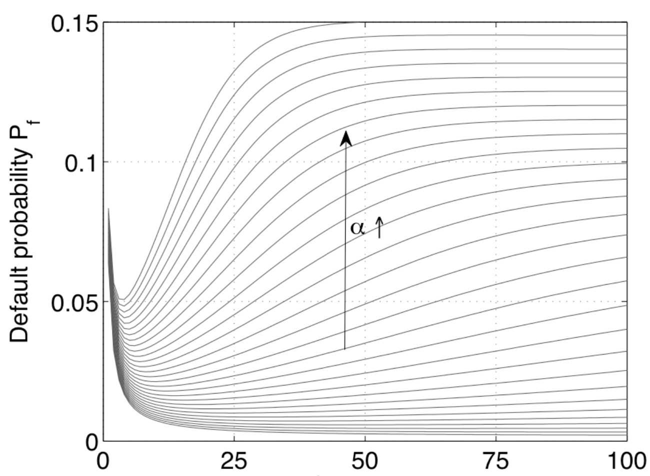


Figure 2. Default probability as function of the diversification, for varying levels of acceleration.

Battiston et al. find that, in absence of the financial accelerator, the interdependence makes the probability of individual bankruptcy and of a systemic crisis tend to zero, due to the sharing of distress as the connectivity and the size of the network increases. Instead the financial accelerator may amplify the effect of the initial shock and it can trigger a third mechanism: a bankruptcy cascade. Moreover, bankruptcies create a loss of "organizational capital" and, if the defaulted entity is a bank, the borrowers incur a cost because they will have to look somewhere else for credit and establish a new relation of trust with a new lender, comporting transaction costs. Together, the three mechanisms may amplify the effect of the initial shock and lead to a systemic crisis if they more than offset the benefit of risk sharing.

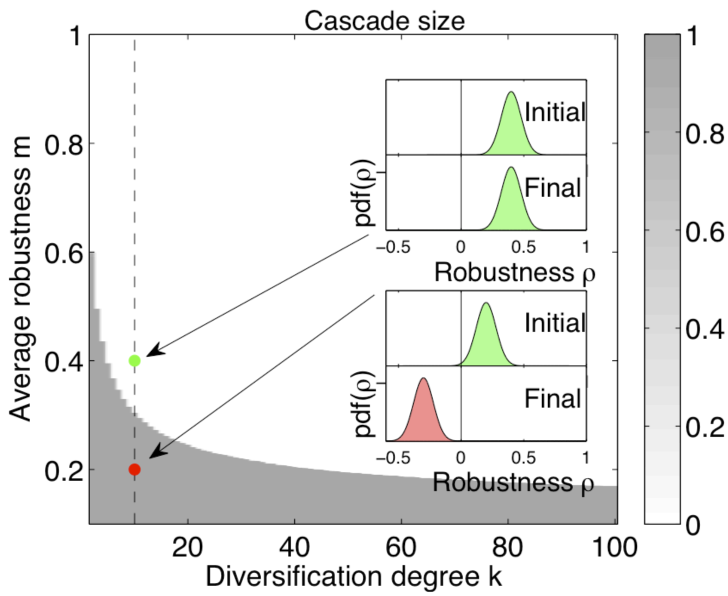


Figure 3. Cascade size as a function of the level of diversification and the average robustness in the system. The color code represents the fraction of agents failing at the end of a cascade. The boundary between large and small cascades decreases with diversification.

The financial accelerator is modeled as a drift term in the SDE. The SDE framework gives the possibility to analytically investigate the impact of the network density on the stability of the financial network. Depending on the initial distribution of robustness, the authors find that there are two regimes, one with small cascades and one with large cascades. Thus, in presence of the financial accelerator, systemic risk does not change monotonically as risk diversification in the credit network increases. Then, there is an optimal level of risk diversification.

In the paper "Default Cascades: When Does Risk Diversification Increase Stability?", the authors analyse both insolvency and illiquidity problems. Indeed the illiquidity problem, through the fire-selling mechanism, can take a solvent bank to become insolvent. Indeed, after a negative shock, chances that the agent defaults have increased, although technically she is still solvent. As a result, short-term creditors have to decide whether to rollover debt to the agent or not, taking into account that the other creditors do the same reasoning. Assuming that they run on the agent only when she is not robust enough, in the face of a run, the bank is forced to sell also the illiquid assets. Hence the nominal value of assets goes down because of distress selling, leading the illiquid bank to insolvency.

In this context, the authors investigate how the size of the default cascade is affected by the initial distribution of robustness and by the level of risk diversification in the network, finding that: i) for relatively ”high” levels of average robustness, increasing connectivity is always beneficial; ii) for ”low” levels, increasing connectivity does not have any effect on systemic risk, iii) for intermediate levels of the average financial robustness, increasing connectivity has first a beneficial and then a detrimental effect.

With methods similar to those explained in the previous paragraph, another field of work studies the impact of bank’s portfolio (composed by assets such as loans, securities, real-estate investments and so on) on the interbank network. Paolo Tasca and Stefano Battiston finalized a new working paper, entitled “Diversification and Financial Stability”, available at: http://web.sg.ethz.ch/wps/CCSS-11-001.

In this paper, banks invest in obligations issued by other banks and in other external assets that may be in a downtrend or in an uptrend. Banks adopt an equally weighted portfolio of external assets, choosing the number of external assets to maximize their expected Mean-Variance (MV) utility function. The authors find that banks’ default probability increases with diversification in case of a downturn and decreases in case of an upturn, then it is desirable in upturn periods, but tends to induce a systemic failure in downturn periods, in line with the robust-yet-fragile property of “connected” networks. Indeed, leverage is positively correlated for all pairs of banks when banks have portfolios of overlapping external assets, that is they engage in similar activities (e.g., mortgages concentrated in specific areas, loans to specific sectors of the economy) and doing so, they are indirectly linked as they are exposed to the same risk drivers. Therefore, when a single bank is close to default, it is likely that several other banks are also close to default. If, at the same time, the financial network of claims and obligations is dense enough, the default of a single bank is very likely to have a systemic impact.

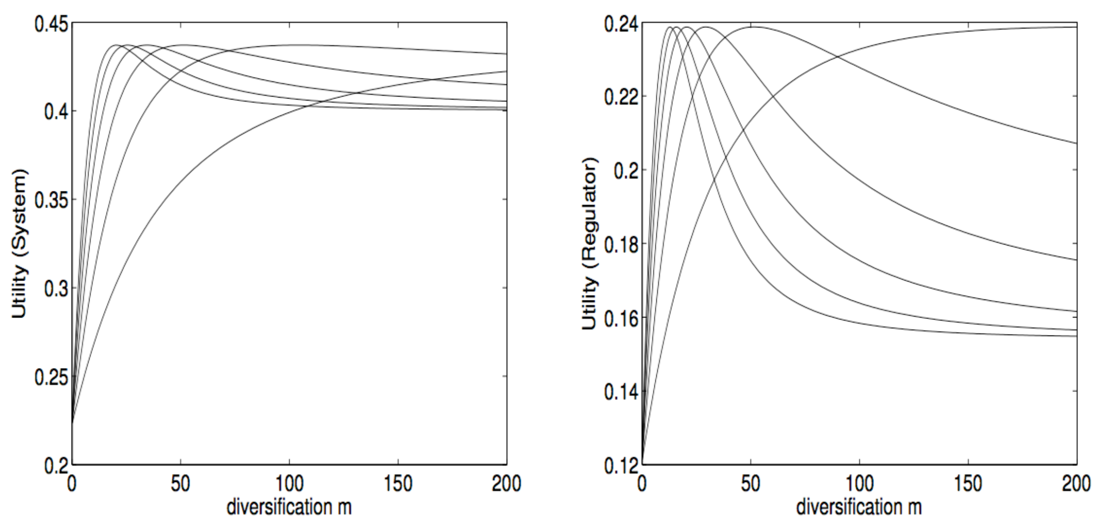


Figure 4. Utility of the bank system versus utility of the regulator as a function of the diversification level for varying levels of growth/recession in the economy. The network that is optimal for the banking system is over-connected for the regulator point of view.

Under the condition of the presence of externalities with "incremental costs" that grow with the number of defaults, because of deadweight costs of systemic failure that exceed the costs of individual failures, the regulator should consider social costs. Tasca and Battiston find that the optimal level of diversification for the regulator is always smaller than the one desirable at individual level. This leads another finding: individual banks' incentives favour a financial network that is overdiversified in external assets compared to the level of diversification socially desirable, with implications for the policy maker to mitigate systemic risk.

All the previous papers develop a research trend that is largely increasing in the last years, with works such as Acharya (2009), Allen et al. (2010); Brock et al. (2009), Haldane and May (2011), Ibragimov et al. (2011), Ibragimov and Walden (2007), Nier et al. (2007), Shin (2008, 2009) and Stiglitz (2010).

T2.2.2 Credit markets as statistical ensembles

In the paper of S.Viaggiu, A. Lionetto, L. Bargigli, M. Longo ("Statistical ensembles for money and debt", arXiv:1109.0891v1), the fundamental methods of statistical mechanics are applied to build a statistical ensemble representation of a simplified credit market. To this purpose the authors adopt the Boltzmann-Gibbs distribution where the role of the Hamiltonian is taken by the total money supply (i.e. including money created from debt) of a set of economic agents interacting over the credit market. In the paper the Boltzmann-Gibbs distribution is not obtained from simulations, instead it is derived from integration over the microscopic variables composing total money supply, which act as the coordinates and their conjugate variables for the given ensemble.

Once the identification between thermodynamic quantities and economic ones is performed, we can take into account 'economic' transformations in which money can be exchanged between different economic systems or work can be performed under the form of a credit expansion.

Although real economic systems are typically not at the equilibrium, this approach can be used in principle whenever we can introduce a given economic conserved quantity. This is the case of markets in which, with some approximation, supply can be taken as fixed. The credit market is an instance of this category inasmuch as the monetary base is determined exogenously by the central bank. The next step in this line of research will allow for a more realistic balance sheet representation of agents, whereby different classes of credit assets and liabilities are introduced.

T2.3 Onset of instability and Self-Organised Criticality (Planned duration Month 24-42)

This line of research aims to grasp a better understanding of the self-organized nature of financial markets, which on its part could help to explain the non-linearity and unpredictability of the latter. In fact, the abrupt and coordinated shifts of investors' sentiment across the financial markets, as well as of banks' willingness to lend across the credit markets, resemble quite strongly the behaviour of physical systems in a critical state, without the necessity of fine tuning parameters in order to maintain the system in such a state. This feature, which has been detected in a variety of complex systems, is known as 'self-organized criticality' (SOC). In other words, systems displaying SOC have a critical point as an attractor. This property could act as a test-bed for agent-based modelling, since realistic models should not limit themselves to reproduce those stylized facts which are at odds with mainstream theory, they should additionally reproduce those facts as the spontaneous, endogenous, outcome of the system's behaviour for a wide range of parameter values.

During the first year, we carried out a preliminary activity consisting in a critical review of a sample of representative agent based models of financial markets, written by M. Cristelli, L. Pietronero and A. Zaccaria ("Critical Overview of Agent-Based Models for Economics" - arXiv:1101.1847). As it turns out, SOC is largely neglected in the ABM literature, which is mostly focused on replicating the main stylized facts of financial markets, while the self-organization of markets is generally overlooked. A notable exception is represented by the "Santa Fe Artificial Stock Market" (Holland et at. 1996), which shows the existence of two stable states, one of which produces a price dynamics with realistic statistical properties, even though the model does not explain how this state can be reached by means of self-organization. Other models, like the "prototype of stock exchange" of Caldarelli et al. (1997) or the Giardina and Bouchaud (2003) model, share this limit.

The model of Alfi et al. (2009) is the first one to propose a mechanism to understand the phenomenon of self-organization of financial markets, i.e. to find out why the empirical time series display a power-law behaviour typical of a critical state without having any exogenous fine tuning. The key element is the non-stationarity of the number of agents that can enter or exit the market depending on the signal they perceive. The entry-exit process leads the system spontaneously towards a regime where stylized facts hold, while all situations without stylized facts are shown to be unstable. In other words, the stylized facts correspond to finite-size effects with respect to time and number of agents. Consequently, we should talk about a quasi-critical state, since power laws appear because of finite size effects, and not in the thermodynamic limit as customary in statistical mechanics.

The model simplicity can be easily exploited introducing more realistic features in a systematic way. The possible extensions include price reaction to an abrupt change in the fundamental price, different strategies, herding in a network, finite wealth and so on. The next step will be the study of portfolio coherence emerging from collective lack of trust and its implications in terms of systemic risk.

T2.4 Immunization strategies (Planned duration Month 24-42)

T2.4.1 Network topology and system stability

The stability of an interconnected system depends directly from the configuration of its connections. It is well known, for example, that scale-free networks are vulnerable to targeted attacks and to epidemic diffusion, requiring targeted immunization strategies of systemically important nodes.

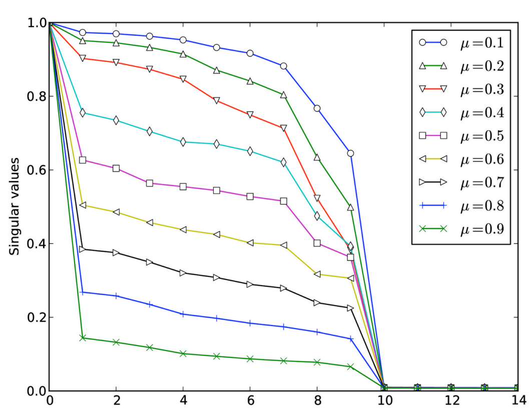
On the other hand, we need very flexible tools to deal with economic networks, which are largely still to be developed. For instance, we wish to work with bipartite, directed and weighted networks, since credit markets exhibit such features, while most part of network theory is developed for simple graphs, which are much easier to handle from a theoretical point of view. Taking advantage of previous works on this subject, our main goal is to devise tools to characterize real credit networks by comparing them with suitable randomized counterparts, and to detect the systemically important nodes through the identification of subsets of highly connected nodes.

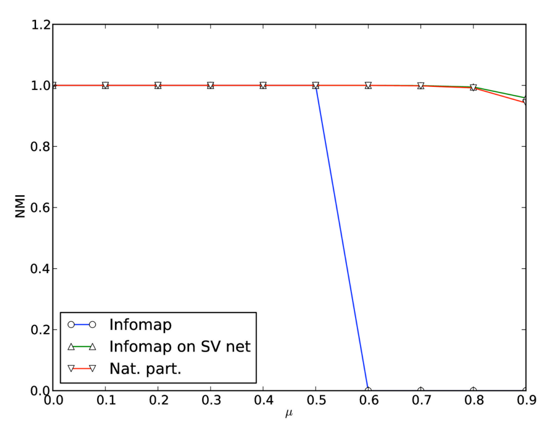
Under this framework, Vinko Zlatić, Andrea Gabrielli, Guido Caldarelli have presented a new approach in their work "Topologically biased random walk with application for community finding in networks" (Phys. Rev. E 82, 066109 - 2010). With the help of a single parameter β, they introduce a bias with respect to ordinary transition probabilities, which is related (directly or inversely) to some network property, such as weights, clustering coefficient, betweenness. Then the authors examine the dependence of the spectrum of the biased transition matrix from the value of β with the help of parametric equations of motion (PEM). In particular, they focus on the spectral gap, i. e. the difference between the first and the second largest eigenvectors of the transition matrix, which measures how fast the RW initial distribution of the system is destroyed in the process of approaching to the stationary distribution, and find that the spectral gap has a well defined maximum when plotted as a function of β. Finally, they apply their methodology to the problem of community finding, exploiting the general idea to enhance the spectral properties of the unbiased transition matrix with the help of biased RW. In fact, it is well known that the number of communities in the network is linked to the largest eigenvalues of the associated matrices, like the Laplacian or the transition matrix, and that for those matrices the corresponding eigenvectors display similar values for nodes belonging to the same community. By using biased RW it's possible to widen the gap between the relevant eigenvalues and the others on the one hand, and to make the relevant eigenvalues larger on the other. The resulting eigenvectors components will separate more sharply nodes belonging to different communities. Further, by using this strategy it's possible to exploit the information conveyed by other network properties (for example edge multiplicity) in addition to edge density.

Regarding the same topic, in a previous work Bargigli and Gallegati (2011) have introduced a test for the null hypothesis that real credit networks belong to an ensemble of suitably defined expected degree networks, which display the peculiar property of having no statistically significant modules or communities. In fact, in this ensemble communities arise only as the outcome of random fluctuations around a module-free expectation. The latter is given by a rank-1 matrix, since the entries of the adjacency matrix are determined by a probability value which is exclusively a function of the (relative) out- and in-weight distribution. This test, which is based on singular value decomposition (SVD), exploits the fact that the singular values of a suitably normalized matrix in this ensemble are linked to the variance of the entries of the same matrix, which can be explicitly determined. By using SVD instead of eigendecomposition, it's immediately possible to apply this test to directed and bipartite networks. On the other hand, all the relevant results linking spectral properties with community structure are confirmed and extended by this approach.

Building upon this results, the authors are working on a generalization of the expected degree model (EDM) for weighted digraphs, which allows to generate random graphs with a modular structure. In fact, the probability distribution underlying the EDM is obtained as a solution of a maximum entropy problem where out- and in-weight distribution are used as constraints. Then it's possible to employ the same maximum entropy techniques to build an ensemble of networks satisfying additional constraints, such as the expected total weights within and outside modules for a given random assignment of nodes to *m* modules. By solving this problem numerically, it is possible to interpolate between a modules - free ensemble of networks (which coincides with the EDM) and a family of increasingly modular ensembles of networks, by controlling for a single parameter μ, which takes a unitary value for the EDM and becomes zero for a network composed of disconnected modules. Simulations performed over samples of such networks show that they display the expected spectral properties, such as a number of large (non-unitary) eigenvalues equal to $m - 1$ for $\mu < 1$, and an increasing spectral gap for increasing levels of μ (Fig.3a).

Currently, this new benchmark model is being applied to test the effectiveness of alternative community/module partition algorithms. In fact, differently from real networks, with artificial networks we fix in advance the community partition, so that we can always verify if the true partition is correctly recovered by the algorithm. The advantage of this new benchmark compared to the existing ones lies in its higher flexibility and generality, which allows in principle to embed many desired features in the artificial networks. By adopting this benchmark, the authors have confirmed the results presented by Lancichinetti and Fortunato (2009) for the Infomap algorithm over a different benchmark (Fig5.b). Moreover, an improvement of the quality of partition has been obtained by adapting the approach of statistically validated networks proposed by Tumminello *et al.* (2011). In fact, it's possible to show that the entries of the adjacency matrix of the benchmark network are binomially distributed random variables. This implies that we can assign a probability value to single entries, 'validating' only those connection with a lower probability value than a suitable threshold (generally determined with the help of Bonferroni correction). In this way it's possible to obtain a unweighted network, whose components represent the 'natural partition' of the original network. Numerical results show that this strategy outperforms Infomap over our benchmark if the average community size is not too low, since it yiels much better results when the value of μ gets higher, i. e. the partition problem gets more difficult to solve (Fig5.b). Only minor improvements seem to be possible by applying the Infomap algorithm over the statistically validated network.





(a) (b)

Figure 5. (a) Average singular values of samples of 100 benchmark random graph with 10 modules for each value of μ. (b) Average Normalized mutual information of the partition produced by alternative algorithms over samples of 100 benchmark graphs with 10 modules of different sizes (minimum: 10 nodes; maximum: 50 nodes) for each value of μ.

Problems

In the current version, the strategy space of banks is described by a simple mapping from a bidding rate to a probability space. When we enrich the model to allow for Markovian strategies which are state-dependent, the mapping will have to pass from a bidding rule to a probability space. This is a non-trivial extension, common to agent based model in the design and implementation phases. Namely the layering of complexity and validation of the model outputs at each layer. We need to enrich the dimensionality of the strategy space, for example by allowing lenders the option to keep hold of their liquidity and by giving banks freedom to either initiate or respond to a trade. We also aim to generate realizations where banks show heterogeneity with respect to their capitalization, their preference of trading partners and their exposure to external assets such as derivatives.

Reaction to problems

We are currently researching the literature on machine learning to help choose the correct representation for the problem of Markovian strategies. The team will meet in the last week of September to agree on a modeling strategy based on his research.

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