Introduction special issue crises and complexity

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Editorial

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The financial-economic crisis has changed the way of thinking of economist and policy makers. In an often quoted opening address to the ECB Central Banking Conference, November 2010, then president of the ECB Jean-Claude Trichet said: "*.. in the face of the crisis, we felt abandoned by conventional tools*". Trichet advocated an interdisciplinary approach to apply complex systems and to develop agent-based models (ABMs) to model financial-economic crises and use these models for policy[1]:

"The atomistic, optimizing agents underlying existing models do not capture behavior during a crisis period". We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. Behavioral economics draws on psychology to explain decisions made in crisis circumstances. Agent-based modeling dispenses with the optimization assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention….

In this context, I would very much welcome inspiration from other disciplines: physics, engineering, psychology, biology. Bringing experts from these fields together with economists and central bankers is potentially very creative and valuable. Scientists have developed sophisticated tools for analyzing complex dynamic systems in a rigorous way. These models have proved helpful in understanding many important but complex phenomena: epidemics, weather patterns, crowd psychology, magnetic fields. Such tools have been applied by market practitioners to portfolio management decisions, on occasion with some success. "I am hopeful that central banks can also benefit from these insights in developing tools to analyze financial markets and monetary policy transmission".

In November 2011 an EU interdisciplinary collaborative project *Complexity Research Initiative for Systemic InstabilitieS* (CRISIS) started taking up Trichet's challenge to develop a complexity interactions agent-based model for the European financial-economic crisis. A particular challenge of the project is to integrate macroeconomic and financial agent-based models as a more realistic description of the financial-economic crisis.[2] This special issue on *Crises and Complexity* reflects some of the ongoing work of this interdisciplinary collaboration between economists, physicists, computer scientists, etc. that has been presented and discussed at various CRISIS workshops in Milan, London, Paris and Leiden throughout 2012–2014.

The special issue consists of 9 papers, the first 3 more focused on macroeconomic ABMs and the last 6 more on financial ABMs and financial networks.

The first contribution, by *Tiziana Assenza, Domenico Delli Gatti and Jakob Grazzini* studies the emergent dynamics of a Macroeconomic Agent-Based Model with Capital and Credit (CC-MABM), building upon the framework put forward by Delli Gatti et al. (2011). A key feature of ABMs is the "bottom-up" approach using simple and "realistic" individual decision rules (heuristics) for consumer and firm behavior. An ABM is the aggregation of all individual decision rules. The main novelty of this model with respect to the earlier work is the introduction of a stylized supply chain where upstream firms – i.e. producers of capital goods (K-firms) – supply a durable and sticky input (capital) to the downstream firms, who produce consumption goods (C-firms) to be sold to households. Both C-firms and K-firms resort to bank loans to satisfy their financing needs. The two-ways feedbacks between firms and markets yield interesting emerging properties at the macro level. The paper shows that the interaction of upstream and downstream firms and the evolution of their financial

[1] Recent discussions and up to date surveys of complexity economics are Kirman (2011) and Hommes (2013), while Bouchaud (2013) discusses applications of statistical physics models to socio-economic phenomena. LeBaron (2006) and Iori and Porter (forthcoming) survey financial ABMs and Delli Gatti macro ABMs, while Tesfatsion and Judd (2006) include many more contributions and surveys on ABMs. Farmer and Foley (2009) stress the importance of ABMs for economics and Farmer et al. (2012) stress the role of ABMs for policy.

[2] A number of other ABMs have been developed for policy analysis, see the recent discussions and overviews in Dosi et al. (2013) and Dawid et al. (forthcoming).

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conditions – in a nutshell: Capital and Credit – are essential ingredients of a *crisis*, i.e. a sizable slump followed by a long recovery.

An ABM with many agents is sometimes said to be a black box in which it may be difficult to distinguish cause and effect. The second contribution, by *Stanislao Gualdi, Marco Tarzia, Francesco Zamponi and Jean-Philippe Bouchaud*, use simple stylized complexity models to explore the possible types of phenomena that macroeconomic Agent-Based models (ABM) can reproduce. Their methodology is inspired by statistical physics, that characterizes a model through its *phase diagram* in the parameter space in order to detect the tipping points that cause critical transitions, i.e. sudden changes, in macroeconomic ABMs. Their starting point is to understand the large macro-economic fluctuations observed in the "Mark I" ABM of Delli Gatti and collaborators. Their major finding is the generic existence of a phase transition between a "good economy" where unemployment is low, and a "bad economy" where unemployment is high in a simple stylized framework. This transition is generically induced by an asymmetry between the rate of hiring and the rate of firing of the firms. The unemployment level remains small until a tipping point, beyond which the economy suddenly collapses. If the parameters are such that the system is close to this transition, any small fluctuation is amplified as the system jumps between the two equilibria. A number of extensions of the model are explored, e.g. with bankruptcy threshold, limiting the firms maximum level of debt-to-sales ratio. This leads to a rich phase diagram with, in particular, a region where acute endogenous crises occur, during which the unemployment rate shoots up before the economy can recover. The effect of simple monetary policies that attempt to contain rising unemployment and prevent crises are also explored. The paper ends with general comments on the usefulness of ABMs to model macroeconomic phenomena and the use of simple stylized models in particular.

How to model the many individual decision rules in an ABM? One approach to discipline the "wilderness of bounded rationality" by empirical guidance is to use laboratory experiments with human subjects. A key feature of experimental macroeconomics is the laboratory study of group behavior, to investigate simultaneously individual decision rules at the micro level, their interactions and the aggregate macro behavior.[3] In the third paper of this special issue, *Tiziana Assenza, Jakob Grazzini, Cars Hommes and Domenico Massaro* study how firms set prices and quantities in a standard monopolistic competition setting, as e.g. in the macro ABMs of Delli-Gatti et al. (2011). The paper present results from 50-rounds experimental markets in which firms decide repeatedly both on price and quantity of a perishable good. Subjects are asked to make both production and pricing decisions given different information sets on individual profits, excess demand and excess supply, and on the aggregate price level. Persistent heterogeneity is a characteristic feature of individual behavior, with about 46% of market followers, 28% profit-adjusters and 26% demand adjusters. Nevertheless, prices and quantities tend to converge to the monopolistically competitive equilibrium and we find that subjects' behavior is well described by adaptive learning heuristics.

The financial-economic crisis has shown that credit networks and leverage are of crucial importance for the spillover of financial instability to macroeconomic dynamics. Credit networks allow risk sharing but also the diffusion and amplification of local shocks into the global economy. The contribution by *Ermanno Catullo, Mauro Gallegati* and *Antonio Palestrini* presents an agent-based macro model with interactions of banks and firms in an endogenous credit network. Banks and firms are linked through multiple credit relations and agents choose their leverage level according to a reinforcement learning algorithm. Simulations are calibrated on balance sheet data of banks and firms quoted in the Japanese stock-exchange markets from 1980 to 2012. The paper aims to build an early warning indicator based on a network financial accelerator mechanism (Delli Gatti et al., 2011; Battiston et al., 2012) in which the amount of leverage is a strategic choice of the economic agents. The early warning indicator is based on the analysis of the dynamic configurations of the credit network. Simulations show that during expansions network concentration rises and the probability of having huge reductions of the output increases. In fact, when some banks are in a central position in the credit network – in terms of both number and size of loans – a shock (for instance, the failure of a large borrower of the bank) may produce a contraction of the loan supply resulting in large systemic effects. The model underlines the importance of the dynamics of the credit network for the resilience of the economic system: when the aggregate leverage level and the connectivity of the network are relatively high, even small local negative shocks may have large systemic effects. Thus, not only agent's size, but also their connectivity has a decisive impact on the stability and resilience of the economic system, emphasizing the importance of turning policy attention from 'too big to fail' to 'too connected to fail'.

During the crisis, increased uncertainty about counterpart credit risk led banks to hoard liquidity rather than making it available in the interbank market. Money markets in most developed countries almost came to a freeze and banks were forced to borrow from Central Banks. Nonetheless there is growing empirical evidence showing that banks that had established long term interbank relationships had better access to liquidity, both in normal times and during a crisis. Relationship lending thus, by supporting liquidity reallocation in the interbank market, plays a positive role for financial stability. The default, or exit from the market, of banks that are important relationship lenders or borrowers may lead to a deterioration of the interbank credit market. In this sense, when establishing if a bank is too connected to fail, regulators should not only look at how connected a bank is, but also at how preferentially connected it is to other key players. Given the potential implications for financial stability, it is useful, i.e. for stress test exercises, to develop simple models that, given a set of constraints, can generate realistic scenarios, including the formation of stable relationships. This is the aim of the

[3] See Duffy (in press) for a collection of recent contributions on the state of the art of experimental macro-economics.

paper by *Giulia Iori, Rosario Mantegna, Luca Marotta, Salvatore Micciche', James Porter and Michele Tumminello* who introduce an agent-based model of interbank trading with memory, in a centralized interbank market with heterogeneous market participants. The memory mechanism is used to introduce a proxy of trust in the model. The memory mechanism assumes that the probability that a lender and a borrower end up trading at a given time step depends on their trading frequency (their heterogeneity), on the number of times in which the borrower borrowed from the lender in the past, and an overall attractiveness of borrowers. Model outcomes and real money market data are compared through a variety of measures that describe the structure and properties of trading networks. These include number of statistically validated links, bidirectional links, and 3-motifs. The model reproduces well features of preferential trading patterns empirically observed in a real market.

Two further papers analyze the implication of new regulations proposed under the Basel III agreement: the new leverage ratio and the banks resolution mechanisms. The new (Basel III) leverage ratio is defined as a minimum percentage (3%) of the capital measure to the exposure measure. One of the impacts of this new approach is that it considerably widens the definition of what constitutes leverage in the banking system, pushing banks to either increase their capital or reduce their intermediation activity. While advocates of tougher regulation generally support this tightening, its critics question if obliging banks to reduce their leverage ratio will increase systemic safety more than it reduces the intermediating role of the banking system, which in effect is the engine of growth for the real economy. The aim of the paper by*, James Porter, Giulia Iori, Giampaolo Gabbi and Saqib Jafarey* is to study this question. The authors present an agent-based model focusing on the linkage between the interbank market and the real economy with a stylized central bank acting as lender of last resort. The tradeoff between stability and economic performance is explored for different structures of the interbank market. The results of the model provide some support to the concerns raised by critics of new Basel framework by showing that on one side low ceilings on leverage ratios can protect banks from idiosyncratic and systemic risk, but they do have an anti-competitive effect which hurts borrowers in the real economy, especially in times when the demand for bank credit is high. On the other side, relaxed leverage ceilings can make banks particularly vulnerable to systemic failure in times when demand for bank credit is low. Thus there appears to be no "one-size-fits-all" solution to financial regulation.

Since the Cypriot Financial crisis in March 2013, which saw the first realization of a bail-in resolution mechanism, there has been an intense 'bail-out versus bail-in' debate to try and clarify which mechanism outperforms the other. Proponents of bail-ins often cite the moral hazard problem of bail-outs. On the other hand, bail-ins are criticized for providing a channel for contagion risks from the failing institution to its investors. *Peter Klimek, Sebastian Poledna, Doyne Farmer and Stefan Thurner* employ and agent-based model to address the question of which of three relevant crisis resolution mechanisms – bail out, bail in and the orderly liquidation of a bank – performs optimally under given economic circumstances. They assess the performance of resolution mechanisms not only in terms of minimizing financial contagion risks, but also in regard to how they impact the entire economy in term of unemployment, economic growth, and liquidity provision to entrepreneurs. An implementation of the "Mark I" ABM of Delli Gatti and collaborators is used and extended by the described crisis resolution mechanisms. A central feature of the Mark I model, as shown by Bouchaud and co-authors, is the existence of a first order phase transition between economic states of low and high unemployment, which is closely related to the refinancing rate offered to firms. The paper shows that the performance of the resolution mechanisms itself depends of which state the economy is, i.e. whether interest rates are high or low. For the low interest regime all three resolution mechanisms perform similar, in the critical interest regime bail-outs and bail-ins both outperform the liquiditation case, while in the high interest rate regime the bail-in mechanism ranks highest.

The recent financial crisis has highlighted the systemic consequences of the use of leverage. If leveraged investors face a leverage constraint, a negative shock in the assets they hold may result in the tightening of their constraint, and force them to sell part of their assets. By selling into falling markets they may cause prices to fall further and leverage to further increase. This dynamics is referred to as a leverage cycle. An important driver of leverage cycles has been identified in Value-at-Risk risk management strategies*. Christoph Aymanns and Doyne Farmer* contribute to this literature by developing a dynamic agent-based model of leveraged investors that invest in multiple asset and are subject to a Value-at-Risk constraint. The authors use the model to study the impact of the parameters of risk management on the dynamical properties of leverage cycles and how leverage cycles might be controlled by regulation policy. In particular they show that bank leverage management can cause recurring patterns of stock price bubbles and crashes which occur in a chaotic regime of the system. When the leverage regulation policy is sufficiently countercyclical and bank risk is sufficiently low the endogenous oscillation disappears and prices go to a fixed point. However, for large values of bank risk counter-cyclical leverage policies still generate volatility and instability. The authors show that this behavior is ultimately due to the symmetry of risk to changes in stock price and suggest a stock return based policy rule, rather than volatility based, on bank riskiness. The effectiveness of this simple rule will depend on the time horizon over which the regulator measures the price movements and the aggressiveness of his response. Interestingly, this relationship is non-monotonic yielding a region of optimal measurement horizon and aggressiveness. The policy is only effective in a relatively small region of its parameter space and careful calibration would therefore be required for effective implementation.

Apart from the interbank market, any other form of liquidity funding, either with the Central Bank or other investors, is collateralized. Repurchase agreements (repo), in which eligible assets are exchanged against cash, are one of the most important sources of funding for both, commercial and investment, banks. Because of the uncertainty regarding the future value of the collateral, the capital lent in a repo is lower than the value of the security at the beginning of the contract, by an amount called the haircut. The haircut covers the risk of depreciation of the collateral and as such it is related to the volatility of the asset. The contribution by *Fabrizio Lillo and Davide Pirino* addresses how a financier should determine the value of the haircut in a repo in order to being protected not just against volatility risk, as typically considered in this literature, but also against systemic risk, given the simultaneous presence of market illiquidity, target leverage, and portfolio overlap. Asset liquidity is a factor because when the financier tries to sell the asset to recover the loss by the potential default of a borrower, he may recover less than the mark-to market price, due to price impact effects. The potential overlap of the portfolio of the defaulting borrower to that of other funds could help spread the distress to other investors if the devaluation of the asset triggers the funds' leverage constraint and induce them to further liquidation of their portfolios. The multi-asset aspect is critical in the model as the value of the haircut is also determined by the characteristics of assets different from the one used as collateral.

Blanchard (2014) recently commented how standard economic models have failed to describe the financial-economic crisis as these models did not pay attention to "*the dark corners where the economy can malfunction badly*". Blanchard stresses the role of nonlinearities and how small shocks to nonlinear systems can have large effects and lead to crises. He notes that standard DSGE models are expanded to better recognize the role of the financial system, and raises the question: "*But should these models be able to describe how the economy behaves in the dark corners*?". Is it enough to extend DSGE models with financial sectors within an otherwise standard rational expectations and optimization framework? Blanchard writes "*Trying to create a model that integrates normal times and systemic risks may be beyond the profession's conceptual and technical reach at this stage*". But there is an alternative underway and it seems wise to put substantial efforts into a complementary research program on agent-based complexity models with nonlinear feedbacks to explore the dark corners of the economy. Much work remains to be done in order to develop a generation of macro-financial ABMs ready to assist policy makers in managing and preventing extreme events and monitor crises. We hope that this special issue reflects some of the exciting challenges and the large potential of the ABM research agenda and the urgent need for more economists to join this interdisciplinary effort.

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