Some elements on Agent-Based Modeling and Economic Theory.

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Abstract

This paper provides a perspective on current trends in agent-based modeling through the lens of the papers that were presented at the 17th WEHIA conference, a selection of which are published in this special issue. To contextualize these contributions, we also provide an historical account of the development of the field and try to situate its current role within economic theory.

Keywords: Agent-Based Modeling, Networks, Heterogeneity, Economic Thought

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1 Introduction

Economics has had a persistent tendency to consider that economic systems are populated by homogenous agents who equally share extraordinary abilities for collecting and rationally processing immense flows of information. The shortcomings of this approach have been recognized early on, in particular by Simon (1959) who brought upon the scene the concepts of limited rationality (bounded or procedural) and learning. Acknowledging the role of heterogeneity and bounded rationality ought to lead economics from a static to a dynamic approach, but the modeling challenges from this perspective were manifold.

At the micro-level, markets have long been thought of as black-boxes that could be represented by the intersection of a supply and a demand curve. Hence, the heterogeneity of markets and of their dynamics, already emphasized by Marshall (see Leijonhufvud 2006), has not been embedded in most micro-economic models, nor has been the impact of institutions or of social phenomena such as as beliefs, imitation or loyalty.

At the macro-level, the tale of the rise of representative agent macroeconomic models is, in part, the tale of the failure of "non-Walrasian equilibrium" models to provide an alternative approach to economic dynamics grounded in the Arrow-Debreu framework that could account for price rigidities and disequilibrium while being amenable to the data and hence relevant for policy analysis (see De Vroey and Malgrange 2011). Indeed, despite the previous efforts of Scarf on the development of a computational framework for applied general equilibrium theory (see Scarf 1967 and Mitra-Kahn 2008 for an historical account), most of the "non-Walrasian equilibrium" contributions (e.g Barro and Grossman 1971 and 1977, Benassy 1975, Drèze 1975) remained at a rather abstract level and mainly focused on the existence and the (in-)efficiency of equilibrium with rationing and price rigidities.

The failure to incorporate dynamics and heterogeneity in economic models is possibly related to the use of inadequate mathematics. As pointed out by Gell-Mann (see Gell-Mann 1995), twenty years later "In much of today’s research on complex adaptive systems, mathematics play a very significant role, but in most cases it is not the kind of mathematics that has traditionally predominated in scientific theory [...] The kind of mathematics that is often used in the simulation of complex adaptive systems resembles the discrete mathematics used on a digital computer to approximate continuous differential equations, but now the discrete mathematics is used for its own sake and not just as an approximation."

Built upon this new mathematics and supported by the development of new computational paradigms, agent-based models (ABMs) play a central
role in the search for alternative economic models. They have allowed to embed insights about imperfect information, technological change and bounded rationality into large-scale macroeconomic models that can replicate both macroeconomic and cross-sectional stylized facts: they provide a dynamic framework fit for policy analysis.

ABMs combine elements of game theory, complex systems, computational sociology, evolutionary programming, and artificial intelligence. Two first and important characteristics are that agents are numerous and interact in markets relations but also possibly in non market relations (i) and that they are heterogenous (ii), by design and/or because of their interactions. Indeed, models of game theory or industrial organization consider interactions but these interactions are between homogenous agents and most of the time, these agents stay identical after having interacted. Four other important characteristics are that (iii) agents are autonomous, and there exists no central decisional power (such as a fictitious auctioneer) controlling the system they constitute. They have limited rationality (iv), a consequence of the complexity that heterogeneity and interactions yield. The rules of the game are modeled precisely (v), including the law and norms that constrain the agents’ autonomy. Finally the mathematics are those of a computer language (vi), and the outcomes are numerical. This implies that the system is discrete and sequential rather than continuous and simultaneous.

Since twenty years, the society for Economic Science with Heterogeneous Interacting Agents has fostered the development of ABMs as an interdisciplinary venture at the interface between Economics, Social sciences, Physics, and Computer Science. The society held its 17th annual conference in Paris in June 2012. The papers presented at the conference have provided a comprehensive overview of the field and we hope that those published in this special issue will give the reader a clear perspective on current trends in agent-based modeling.

The aim of this introduction is to give some elements of the historical and theoretical context for the papers of the issue. Therefore, we give an historical account of the development of agent-based modeling, analyze its relationships with the neoclassical corpus and the concept of equilibrium, and review some of its important contributions to the understanding of micro- and macro-economic dynamics.

The origins of agent-based modeling can be traced back to Orcutt’s invention of microsimulation in 1957. Microsimulation models were initially funded by governmental agencies in order to test the design of economic pol-
icy on topics such as the age of retirement, social benefits or tax policy (for instance Orcutt, Merz, Quinke, 1986 and Harding, 1996). Hence their objectives differ from those of agent-based models, which have been developed as tools to advance research in industrial organization, macroeconomics, and economic theory. However the methodologies share the same fundamental principles, which are put forward in Orcutt’s (1957) seminal paper: "this type of model consists of various sorts of interacting units which receive inputs and generate outputs; The outputs of each unit are, in part, functionally related to prior events and, in part, the results of a series of random draw-ings from discrete probability distributions". As a matter of fact a few models developed a real agent-based approach without being labeled as such, since the term had not been invented yet. Section 2 of the paper emphasizes how ABM have been conceived on the basis of the Microsimulation Models, and yet have departed from them.

From a point of view centered on neo-classical economic theory, the history of ABM would appear as a movement, which started as a run away from the "equilibrium agent", representative and holding rational expectations, to eventually reach the point where both equilibrium and disequilibrium can be subsumed as properties emerging from the dynamics of economic systems with heterogeneous interacting agents. This movement is underlined in Section 3.

Finally, in addition to enrich the macro-economist toolbox, agent-based modeling can change the way economic analysis is conducted at the micro level, and help to better understand the influence of behavioural ecology on markets dynamics. From an equilibrium-centered perspective, markets are black boxes lying at the intersection of an offer and a demand curve, and variations in prices and quantities exchanged are simple adjustments of the equilibrium state due to exogenous perturbations. Agent-based models rather emphasize the spontaneous evolution of markets towards a stable or an unstable situation (as with self-organized criticality). Their results are primarily driven by individual interactions such as word of mouth, mimicry or network effects that constitute the micro level of the system from which emerges, at the aggregate level, offer and demand curves. Section 4 explains how the ABM toolkit has contributed to build a theory of markets instead of a market theory. The conclusion follows.
2 From Microsimulation models to Agent-Based models. One broad methodology.

In this section, we give an account of the apparition of ABMs over 50 years ago under the name of microsimulation (or microanalytic) models and of the development of a second generation of ABMs with a clear macroeconomic focus in the 70’s, 80’s and 90’s. On the basis of this historical survey we aim to show that a closer integration between the developments of microsimulation models and ABM would be fruitful in order to ascertain the status of ABMs as alternatives to orthodox economic models.

2.1 The Microsimulation tradition as the founding stone for ABM

As pointed out by Orcutt (1957), the Microsimulation models (MSM) consist in the interaction of various sorts of units. More broadly, the features of MSMs match the six fundamental characteristics of ABMs described in the introduction. The agents are many and interact, they are heterogeneous and they are autonomous. No central control over their behavior by some fictitious auctioneer is admitted. Orcutt’s emphasis on microeconometric measurement of behavioral drivers, implies boundedly rational decisions. If he does not deal in depth with institutions, except with some markets, the sixth feature of ABM, numerical computation, is central to microsimulation. The outcomes of the interactions are computed numerically and the system is recursive, and dynamic. No simultaneous equations are used (Orcutt, 1957, p.119), but the period should be short (often a week). Just as a Statistical Institute would do, the individual outcomes can be aggregated by mere summation to obtain aggregates such as the GDP, and ratios, such as the unemployment rate, can be computed. Distributions can also be obtained.

Orcutt’s vision was that MSM could be an alternative method to macro models à la Tinbergen-Klein and interindustry models à la Léontieff, in order to model "National economies". MSM were developed with different methodological variants, aiming at different applications. A main feature of these models is to represent the heterogeneity of the agents, behaviors, and

\[3\] Ballot (1987) offers a typology of the microsimulation models in 9 classes and the view that ABM correspond to the best theoretically grounded classes of microsimulation models.

\[4\] Orcutt' autobiography (1990) makes this extremely clear.

\[5\] Baroni and Richiardi (2007) provide a recent and compact survey of Orcutt’s methodology and diverse types of microsimulation models, but do not investigate the relations with ABM.
outcomes. The aim was to provide policy advice to governmental agencies, mainly on tax and transfer issues related to individuals and households (this explains that the firms were not modeled as agents). This required high precision and large data collection, which was (and remains to a lesser extent) a costly process. Orcutt’s wish to obtain macroeconomic outcomes from the individual interactions has not been pursued by the builders of MSM. Many models are static (for instance Beeboot, 1986, on the impact of the social program of the Reagan administration), i.e. they examine the effect of a policy change on a population of individuals or households, taking their characteristics as given. Two types of results are obtained, the distributional outcomes, and the aggregate cost of the policy. The subsequent behavioral response is usually not taken into account. These static models allow to obtain rapidly predictions about the impact of tax/subsidy programs, yet they are close to accounting, and the absence of economic behavior prevented so called second round effects and also limited their adoption in academic economics.

Dynamic microsimulation models generate life trajectories for the agents, and can also simulate endogenously the death of agents and the birth of new agents (see for example Galler and Wagner 1986 model of life cycles in Germany). This is a first methodological step ahead. These models are intended to compute for instance effects of retirement systems for which they have no competing substitute. However the method provides also a tool to take into account the effect of an agent’s history on its future through CV effect on its life. This is another important step. Agents can also learn from their past experience for their future decisions, which involves two major steps: apply decision rules, and revise them. The model is then characterized by path dependency, both at the individual level, and also at the aggregate level. It frees research from the unrealistic simple markovian processes used in orthodox transition models (e.g of the labor market or of innovation). Moreover these dynamic models can take into account sequential interactions between agents. Orcutt mostly developed this type of dynamic microsimulation models with interactions and focused more on demography and the labour market than on production and trade. As a matter of fact, in his models markets are not explicitly represented through the interactions of agents’ decisions on the supply and the demand sides. In particular, firms are not represented as agents. The absence of markets is one of the major weaknesses of the existing dynamic microsimulation models. Orcutt and the other MSM modelers chose not to write the decision making algorithms for both sides of the market, and to model only changes in observed transactions for goods, and the transition

\footnote{Although some models simulate cohorts that do not interact, in order to avoid the modeling complexities and the computational load induced by interactions}
rates between states for individuals, on the basis of conditional probabilities, often estimated on microdata\footnote{See Baroni and Richiardi (2007), p.27 for the specifications}. Yet the macroeconomic perspective remains in some of Orcutt’s work. He claims to close the microanalytic part of the model DYNASIM corresponding to the labor market and demography with an auxiliary macroeconomic model (Guthrie \textit{et al.}, 1972). There are feedbacks between the two parts of the model. The idea of providing a detailed agent-based model for a subset of the economy and of closing by a macromodel or a Computable General Equilibrium model was and remains a promising idea to obtain a very detailed model for policy advice in a specific area and yet keep a limited size (see Spadaro, 2007 for an introduction).

### 2.2 ABM models are a long tradition.

Building on Orcutt’s vision, but with the definite objective to model entire economies, two researchers independently and simultaneously have built macroeconomic ABM in the 70s\footnote{This may not pay tribute to some other pioneers who did a less cumulative research over time. See Orcutt (1990). Moreover we leave aside some ABM models of markets built in the 70’s. They will be mentioned below.}. Bergmann (1974) published the TRANS-ACTIONS model which is able to generate standard macroeconomic aggregates such as: consumption, saving, money holding, financial-asset acquisition, real investment, production, employment, wages, prices, and interest rates\footnote{The full description of the model is given by Bennett and Bergmann (1986), on which we rely here.}. The model is based on individual agents: 10 firms, a bank, a financial intermediary, a federal government, a local government, a monetary authority, over 700 employed and unemployed workers who are members of households that consume and that hold assets. An agent (firm)'s experience and situation are kept track of and enter the decision making process. Money balances for agents are computed and the model would now be called stock-flow consistent. All the transactions are done at the microeconomic level, and the aggregate variables are then computed in the model. Then a scaling factor is applied and provides the outcomes for the US economy. Microdata bases have been used to initialize the households. Decisions are made once a week and the model is completely recursive. Expectations are taken into account to model real investment and portfolio adjustment. Otherwise the decisions are simple rules, and Bergmann’s emphasis is on the constraints (legal, accounting identities) that impinge at the agent level. Bergmann adopts the unusual methodological view (even within the ABM community) that these constraints are a major determinant of micro and macro behavior, when most...
microeconomists concentrate on modeling choice, and when macroeconomic models have impossibilities in modeling some of these constraints, for instance the flow of funds between agents of one sort (Bennett and Bergmann, 1986, p. 7). The Transactions model is calibrated to US macroeconomic data in a fairly elaborate way and with results which appear remarkable for the time. The model has also been used for policy experiments.

The “accounting view” pioneered by Bergmann finds a very strong echo in the contemporary literature. Some recent agent-based Post-Keynesian models take it as fundamental to generate disequilibria (see Bezemer, 2010 for a survey of the theoretical points, Seppecher, 2012 for a simple model). More broadly, the increasing role of financial constraints have opened up a wide range of investigations for agent-based models focusing on the impact of accounting and financial constraints on the economy. For example, the contribution by Biondi and al. published in this issue investigate in an agent-based model, the impact of accounting and market structures on share price formation. The contribution by Raberto and co-authors to the conference uses the Eurace artificial economy to validate the macroprudential regulatory framework put forward in the Basel regulations. Last but not least, contributions that follow-up on Delli Gatti and Gallegati models of financial fragility (in particular these by Russo and al., Ricetti and al., Desiderio and al. published in this issue) are mainly driven by the impact of financial constraints on agents’ behavior.

Contemporaneously to Bergmann, Eliasson (1977, 1984) has built a macroeconomic endogenous growth ABM simulating the Swedish economy, MOSES (Model for Simulating the Economy of Sweden). The model proposes a theoretical framework that is an alternative to the neoclassical models. It is used for analyzing the relations between the short run and the long run and making policy experiments. For that purpose it was calibrated upon Swedish data. Firms (225 at start) are the only heterogenous agents. The individuals are aggregated into one worker-consumer agent. Two other agents are a bank, and the government. An exogenous foreign sector completes this small open economy. There is a labor market on which firms set their own wage, and a credit market where interest rates are set endogenously and credit can be rationed. There is an input output structure filled by four goods markets in which firms interact. The model is stock-flow consistent, accounting for production and monetary flows, with the quarter as the basic period. The

\[10\] The model has given birth to over 50 publications and extended versions are still being developed. The model is fully documented in a series of books, notably the version for PC by Taymaz (1991).
number of firms evolves endogenously: new firms enter in profitable sectors while bankrupted firms exit from the system. Firms are initialized with real data, what eases the stabilization of the model. This appears as a solution to a general and important problem with ABM that tend to have a chaotic behavior for a long initial period (or even get out of control if path dependency is important) when initialized with random data. It is worth mentioning that the great care Bergmann and Eliasson have taken for the initialization and calibration of their models seems to have caused wrong to the models reputation: it makes them look like detailed MSM specific to the US or the Swedish economy, whereas the real objective was to obtain new theoretical results in growth and fluctuations theory, based on micro founded decisions. Presently many ABM with a theoretical objective do not do otherwise since they use the reference to a specific advanced economy (generally the US) to set the parameters and reproduce some stylized facts.

The originality of the model relies on the merging of three theoretical traditions. The first is the detailed Schumpeterian framework (entry and exit, endogenous waves of innovation), the second is the Keynesian feedback of workers-consumers incomes on the demands for the goods, and the third is the Wicksellian tradition which makes the firms set a target net rate of return on capital and determines investment and employment on the basis of adaptive expectations. Mistakes are continuously done and corrected (see for instance Eliasson, 1991a, p.154 for a synthesis and the equations). Firms compete on the markets and may fail if they make too many mistakes. Another feature is the use of boundedly rational rules by the firms. A number of these rules come from a large enquiry on business firms decision procedures made by Eliasson (1976) just before building the model. Additionally, a calibration procedure for the model has been developed by Taymaz (1991).

MOSES can be seen as a precursor to recent macro-economic agent-based models in many respects. On one hand, it emphasized the existence of a trade-off between short run efficiency and long run growth, the fact that entry is a major factor of growth, and that Keynesian feedbacks have a long run effect on entry. This is reminiscent of the results of the Keynes plus Schumpeter model developed by Dosi and co-authors (2013) whose main results were presented at the conference. On another hand, the observation of actual management practices to guide the choice between different boundedly rational rules in ABM is very close to the approach used by Dawid et al. (2012) in Eurace and of the contribution by Neugart and co-authors to the conference.
2.3 The diverging experiences of the MSM and the first ABM models.

On the one hand, microsimulation models have been developed all over the world to advise policy makers and are an established tool. On the other hand, the preceding shows that, starting from the initial microsimulation vision of Orcutt, some full blown macroeconomic ABM have been developed in the 70’s, and published in the best rated journals but, for a long time, stayed largely ignored by the economic community. A first reason is that they were long to build, and required a team effort. A second reason is that they used bounded rationality, which requires choosing among a host of different behaviors while the behavior induced by perfect rationality is assumed to be unique\textsuperscript{11}. Third they encapsulated unorthodox theorizing, leaving aside the equilibrium concept for a Wicksellian, Keynesian and Schumpeterian synthesis (MOSES), or a flow-of-funds disequilibrium modeling (TRANSACTIONS). A fourth reason is that the ABM are not analytical and, even if Monte-Carlo methods are used to average out the stochasticity, they provide results for a specific set of parameters’ values, one among an infinite number. Initializations have been carefully done in the MSM tradition and calibration methods have been tried but they were computationally too costly to be used in a systematic way in order to find the set of parameters that would optimize the fit to some real variables, and systematic sensitivity analysis was also impossible. Yet these first studies (1975-1998) have built micro-to macro models with compromises which kept the essence of the overly ambitious attempts of Orcutt to model entire economies with the two features of having the model based on only individual agents and on completely microeconomic data. They have paved the way to the burst of new models in the mid 2000’s.

3 Equilibrium and disequilibrium in ABM.

From the 1990s onwards, the agent-based research program has been invigorated by increasing interactions with economic theory. In a negative mode, an increasing number of agent-based models have been developed in reaction to the rise of the representative agent and the eviction of disequilibrium and heterogeneity from the mainstream research program. In a positive mode, the evolutionary and Schumpeterian approach to technological change pioneered by Nelson and Winter (1974, 1982) and Greenwald-Stiglitz (1993) theory

\textsuperscript{11}If perfect rationality is unique, each orthodox researcher makes a huge number of assumptions on the environment which are his own choice and arbitrary.
of the financially constrained firm have given rise to new strands of agent-based models approaching macro-economics respectively from the industrial and the financial perspectives. These two approaches have converged in recent years. A number of the contributions that have been presented at the conference and published in this issue are outcomes of this research program.

3.1 Beyond Equilibrium

The evolutionary approach to technological change of Nelson and Winter (1974,1982) combines insights on innovation and industrial organization by boundedly rational firms in order to provide an alternative to the neoclassical theory of technological change based on the optimal growth paradigm. Building on this early contribution, agent-based models have been developed by Chiaramonte and Dosi (1993), Verspagen and Silverberg (1994), Ballot and Taymaz (1997,1998,1999) that could account for stylized facts such as the skewed distribution of firms’ size, the persistent technological and behavioural heterogeneity among firms, the clustering in time of the major innovations, and the possibilities of phases of locks-in with a low growth (see Dawid, 2006 for a survey). Recent models (see Fagiolo and Dosi 2003, Deissenberg et al. 2008, Dosi et al. 2010 for important milestones) have introduced households as heterogeneous agents and evolved into more complete macroeconomic models. Among the most recent vintages that were presented at the conference, Dawid et al. (2012) embed multiple regions and heterogeneous skills in order to investigate labor integration policies while Dosi et al. (2013) combine Keynesian mechanisms of demand generation, a Schumpeterian innovation-fuelled process of growth and Minskian credit dynamics in order to investigate the interplay between income inequalities, fiscal policy, financial crisis and economic growth.

A second strand of research started from the investigation of linkages between finance and macroeconomics and is based on the Greenwald and Stiglitz (1993) theory of the financially constrained firm. These models represent economic systems as credit and production networks populated by heterogeneous interacting agents. They have been able to reproduce a wealth of aggregate and cross-sectional stylized facts such as endogenous business cycles, nominal GDP growth or unemployment rate fluctuations but also the distribution of firms’ size (see Delli Gatti et al 2005), the correlation, over time and across firms, of output, growth and bankruptcies (see Battiston et al. 2007), and the emergence of network-based financial accelerator mechanisms (Delli Gatti et al. 2010). The latest vintages of this class of models published in this issue embed respectively a government sector (see Ricetti
et al.) and an interbank market (see Grilli et al.) These have conserved the ability to reproduce aggregate and cross-sectional stylized facts and moreover yield specific insights on economic policy. In particular, Ricetti et al. clarifies the role of the government sector in dampening business-cycle fluctuations while the framework developed in Grilli et al. allows analysing the impact of market connectivity on bankruptcy waves and business cycle fluctuations.

The comparison during the conference of the latest vintages of models in the “evolutionary technological change” and in the “financially constrained” tradition suggested that those two strands of literature have eventually converged. They now provide comprehensive, contextual and micro-founded models of economic systems, generally consisting of a labor market, a consumption good market, a capital good market and a credit market. These models consistently reproduce a large number of stylized facts. The main challenge they face is now to provide quantitative insights (e.g. via forecasting) that surpass these offered by DSGE models or recent growth models integrating cycles such as the paper of Borges, Fabio and Teixeira in this issue. A necessary step in that direction is the calibration or the estimation of ABM.

In this respect, a major issue is that, in slight contrast to an equilibrium path whose nature is from that point of view uniform, the dynamics of ABM are generally characterized by a transient period which precedes the establishment of the dynamical regime(s) of interest, those where the stylized facts the model aims at representing do hold and in which the calibration/estimation shall take place. Part of the solution to this issue could be provided by an increased usage of micro-data in the initialization process as underlined above, part could be provided by the analysis of the relationships that ABM entertain with equilibrium for which some elements are given below.

3.2 Beneath Equilibrium

In the initial phase of its development, the natural step for agent-based modeling was to abstract away from the notion of equilibrium and to push forward its own research agenda centered on the idea that economic dynamics shall emerge from the decentralized interactions of heterogeneous agents. Yet, two contributions by Gintis (see Gintis 2006, 2007) showed that this research agenda could also contribute to the resolution of pending problems in general equilibrium theory. Indeed, Gintis showed that the adaptive behavior of decentralized traders could lead to the emergence of equilibrium even in settings
that where well known for their dynamic instability under the tâtonnement process (e.g. this of the Scarf economy, see Scarf 1960). Hence agent-based models could provide the dynamic foundations for general equilibrium that had been lacking since the advent of the Sonnenschein-Mantel-Debreu theorem (see Sonnenschein 1973, Mantel 1974, Debreu 1974).

This contribution helped to clarify the relationship between agent-based models and existing theory. On the one hand it reinforced the bridge between agent-based modeling and evolutionary game theory (see Peyton-Young 1993, Dawid 2007). Indeed, analytical counterparts to Gintis results can be obtained thanks to evolutionary game theory (see Mandel and Botta 2009, Mandel and Gintis 2013), which also provides an interpretation of the emergence of a general equilibrium in an adaptive setting as the adoption of a social convention (see Jaeger 2012). On the other hand, and more importantly, it opened the way for a systematic investigation of the relationships between agent-based and neoclassical economics along two complementary lines.

First, as put forward in Guerrero and Axtell (2011), "agentization" can be used systematically to test the validity of equilibrium models. "Agentization is the process of rendering neoclassical models into computational ones. This methodological tool can be used to analyze and test neoclassical theories under a more flexible computational framework. [...] We propose that, by classifying the assumptions of a neoclassical model, it is possible to systematically analyze their influence in the predictions of a theory." Initial contributions in agentization have appeared recently. Among these, Guerrero and Axtell (2011) reproduce the main results of Gabaix (1999) on the origin of Zipf distributions in economics thanks to an agentified model without assumptions such as equilibrium, rationality, agent homogeneity, and centralized anonymous interactions. This method has then been applied to different fields of economics such as the analysis of the labor market or the financial market. Gaffeo et al. (2012) populate the textbook full-employment neoclassical macroeconomic model by a large number of bounded-rational, autonomous agents, who are repeatedly engaged in decentralized transactions in interrelated markets. They show that their fully decentralized multi-market system admits the possibility to attain the Walrasian full-employment equilibrium, but also that serious coordination failures emerge endogenously as learning mechanisms and institutional settings are varied. Lengnick et al. (2013) develop an agent-based of a monetary economy that is "well suited to explain money creation along the lines of mainstream theory". They analyze the impact of interbank lending on the stability of the financial sector and
find that an interbank market stabilizes the economy during normal times but amplifies systemic instability, contagion and bankruptcy cascades during crises. Considering a situation with imperfect information, Salle et al. (2012) investigate the shift to decentralized learning in a New-Keynesian Macroeconomic Model. They obtain rather negative results, as they show that "social learning does not allow the agents to correctly learn about the interdependence between markets, because of the emergence of coordination problems that result in insufficient labour supply and depressive dynamics".

More recently has appeared in the literature an approach to equilibrium in agent-based modeling, converse to the one used in agentization: it starts from a purely decentralized model and explores the parameter space in order to identify subsets of parameters which lead to the emergence of an equilibrium and subsets which lead to the emergence of a disequilibrium regime. As preliminary contributions in that direction, one can cite Ashraf et al. (2011) where equilibrium is used as a benchmark to measure the influence of the banking sector on macroeconomic performance. An other interesting article is the one of Gualdi et al. (2013) which demonstrates the robustness of phase transitions between equilibrium and disequilibrium in agent-based models of financial fragility or the one of Mandel et al. (2013) who introduce price dynamics in a setting à la Delli Gatti et al. (2010) and show that financial constraints are key determinants of the emergence of an equilibrium or a disequilibrium regime.

An interesting feature of these contributions is that they place equilibrium and disequilibrium on the same footing, as emergent properties of a system of heterogeneous interacting agents. This duality could be exploited in order to develop more quantitative insights. The equilibrium regime could be used to calibrate or estimate the model. One could then shift to the disequilibrium regime in order to analyze the characteristics of business fluctuations, financial crisis, or technological change, and to run policy experiments.

3.3 Beyond agent-based macroeconomics.

If our reading of the recent literature is correct, agent-based modeling is about to deliver the kind of output it was calling for in macroeconomics: a model based on heterogeneous interacting agents that is fit for quantitative analysis. This might be an important input for a return to theory at the macroeconomic level. This is already anticipated in some contributions (e.g. Aoki and Yoshikawa 2011, Assenza and Delli Gatti 2013, Di Guilmi et al. 2013), which put forward a macroeconomic theory based on the distribution of macroeconomic aggregates rather than on their average values.
as in the representative agent setting. Agent-based modeling will have a role to play as an experimental set-up within which one could test these newly developed theories. In the meantime, its recent successes suggest that agent-based modeling could expand its scope of investigation beyond the traditional micro/macro realm of neoclassical theory. In particular, very large scale agent-based models currently being developed to grow economies from the bottom-up, starting with the emergence of firms and institutions, could be fruitfully linked to the infra-marginal analysis pioneered by Xiaokai Yang (see Cheng and Yang, 2004 for an introduction).

4 The ABM contribution to the analysis of markets.

As underlined in the preceding section, ABM have been of a great help to improve our understanding of macroeconomics dynamics. At the other extreme of the scope of economic analysis, this concerned with the micro-structure of markets, neoclassical theory adopts a rather uniform view according to which each market can be equally well represented as the intersection of a supply and of a demand curve. This does not do justice to the actual influence of the specific characteristics of the goods exchanged, the individual particularities (and the complex interactions that ensue) and the market design (which largely determines the level of information).

ABMs on the other hand can take into account these specificities and represent the market as emerging from the interactions between individuals and/or organizations. In particular, they can account for the fact that transactions are the outcomes of different phenomena such as bilateral negotiations, social relationships (see Kranton et al 2002), beliefs, imitation, loyalty. They can also yield insights on the search process at play on the market\(^{12}\).

The importance of these phenomena is particularly well documented for financial markets but they are also of concern on the labor market or the markets for complex goods (goods for which quality, even a posteriori remains difficult to assess). For example, in the latter context, recent contributions (see Moreno and Wooders 2010 among others) have shown how a decentralized market can be more efficient in revealing the real quality of a good than a centralized one.

\(^{12}\)There exists a huge literature in theory of search but, as far as we know, individual strategies are given exogenously and what is considered is not the emergence of different search strategies but the influence of a priori strategies on the outcomes.
In the following, we describe how ABM allow to integrate in a formalized approach the main characteristics of these very different markets, how they help to better evaluate the importance of these different causal variables on the functioning of the market (see Bargigli et al. 2014) and point towards interesting contributions to this literature that were presented during the conference.

4.1 ABM and the markets for complex goods

In a setting where goods are heterogeneous in quality and information is asymmetric (because only producers have full information concerning the quality), an important problem for the consumers is to evaluate the quality of the good they wish to consume. A first way to reduce the asymmetry of information is to implement an efficient system of quality certification (as suggested by Akerlof 1971). Another way to favor better evaluations of quality consists in selling goods of different characteristics through different markets’ organizations.

There exist two main types of markets’ organization that differ by the way information circulates: centralized markets (which mainly correspond to auction markets) and decentralized ones (where the transactions are bilateral). Both types of organization can be present on most markets (although on the labor market, the centralized form is very rare). Whereas economists consider that auctions markets insure the same level of information to all the participants, this is far to be the case on negotiated markets. What are then the self-organizing capacities of decentralized markets? This question was already asked by Schumpeter (1934) and Hayek (1948) and is far to be resolved.

Agent based modeling contributes to the debate by building a virtual framework that captures key aspects of decentralized markets such as heterogeneous interactions, limited information or strategic pricing. Another important aspect accounted for is the self-seeking behavior of agents with different learning capacities and the relationship between these behavioral features and the convergence of the market to a stable state (or not). An example of such contribution is the work on price discrimination on Marseille’s fruits and vegetables wholesale market presented at the conference by Kirman and co-authors.

A seminal work in this literature is this by Gode and Sunder (1993), which reports market experiments in which human traders are replaced by "zero-intelligence" agents submitting random bids. Traders have reservation prices and this is sufficient to produce efficient auctions. These authors explain how allocative efficiency of a double auction derives from its structure,
independently of trader’s motivation, intelligence or learning capacities. It then seems that the presence of rational individuals is not necessary to observe at the aggregate level a rational "behaviour". These results are in line with Becker’s remark that "households may be irrational and yet markets rational" and can be seen as an effect of Adam Smith’s invisible hand.

Once admitted the idea that markets need to be organized to be efficient (cf. Stiglitz 1976), an important task for policy makers is to design the markets appropriately. The literature does not give a definitive answer about the superior efficiency of one type of markets (auction markets) on the other (bilateral markets). Milgrom (1986) and Milgrom (2004) show that auctions are more favorable to sellers than buyers, in the sense that they absorb the whole buyers’ surplus. This result has been reinforced by Bulow and Klemperer (1996), who demonstrates that the auction is always preferable when bidders’ signals are independent. More recently, some results, mostly based on empirical or experimental evidence, weaken the idea of auction dominance. Progrebna (2006) reports on a natural experiment in the British television show "Bargain Hunt", which offers a good opportunity to compare bilateral bargaining with auctions. It appears that auction prices are lower than negotiated prices. Kirman and Moulet (2009) compare two type of selling mechanisms (a descending auctions and a negotiated market) through an ABM. Because in the real world it is rather complicated to find situations where both mechanisms co-exist, these authors have simulated populations of artificial agents (both sellers and buyers) who learn, through experiments to use specific behavioral rules (or strategies). Two types of learning are considered at two different time scales: daily information learning and rules learning through experiments. They show, through simulation that if the auction is more interesting for "rich buyers" - the ones with the higher reservation prices who pay less on average than through bilateral transactions -, the negotiated market, where the distribution of price is wider, allows "poor buyers" to purchase. We see how these results come to mitigate Milgrom’s assertion, relating the efficiency of a mechanism to the characteristics of the population.

Willing to analyze a market as a complex system, a lot of authors have concentrated on the study of fish markets. Individual behavior is particularly complicated to understand on these markets. Yet their economic analysis has a long history (Pareto 1896, Thornton 1870, Marshall 1890) because they have been considered as good representations of exchange markets. Recent results about the dynamics of fish markets were presented at the conference by Mignot and co-authors who investigate the relationships between difference in selling mechanisms and difference in prices on the Boulogne sur mer fish market and by Guerci and al. who proposed an agent-based computa-
tional model of the sequential Dutch auctions: in the Ancona fish market.

A persistent result, concerning the functioning of fish markets is that, although the price for different units of a same good may vary, the distribution of prices across the market changes remarkably little over time: this aggregate behaviour is documented on different fish markets (see Kirman and Vignes 1990, Vignes and Etienne 2011, Weisbuch et al. 2000 and Gallegati et al. 2011). This observation also reinforces the results obtained by many agent-based models, which show that downward slopping aggregate demand curve is not derived from similar properties at the individual level, in line with the pioneering analyses of Grandmont (1987), Gode and Sunder (1993) and Hildenbrand (1994).

4.2 ABM and the financial markets.

Generally speaking, assuming that human behavior leads to stable, self-regulating markets, with prices fluctuating around the equilibrium can possibly be reasonable when dealing with systems with a high level of rigidity (institutional or others) and slow dynamics. When it comes to very reactive systems such as financial markets, the theory of complex systems shows that although a system may have an equilibrium state, its basin of attraction may be very narrow and that the system rarely settles there. Being very sensitive to small perturbations, the equilibrium becomes less relevant for the understanding of the system. In other words, analytically tractable traditional models are not well-suited to study bubbles formation and crisis situations (Iori and Porter 2012, Bouchaud 2008, Farmer and Foley 2009).

Arguing that there is no place in neo-classical economics for the analysis of crisis, Kirman 2010 suggests that economic models should drop the unrealistic representative agent basis for aggregate behaviour and the even more unreasonable assumption that the aggregate behaves like such a "rational" individual. He rather proposes to analyze the economy as a complex adaptive system, and to take the network structure that governs interaction into account: ABM is a perfect tool to represent unstable systems distorted by crashes and booms and driven by non-linear dynamics.

To our knowledge, one of the first attempt to analyze the heterogeneity of behaviours on a financial market is the one of Chan et al. (1999) who use agent based modeling to analyze dynamic markets with asymmetric information, learning, and uncertainty. Their model simulates a repeated double-auction market populated with artificially-intelligent traders having heterogeneous learning capabilities. Instead of making ad hoc behavioral assumptions (what is often the main weakness of ABM), the authors use data from experimentations to validate and calibrate their model. They show
that simple artificial intelligent agents endowed with only rudimentary computational learning abilities can replicate several features of human-based experimental markets. They provide a market structure which enables the agents to trade with each other, and specify the preferences and learning heuristics of all market participants: it is the interaction of these two sets of specifications that yields their main results. Under different constraints (homogeneous preferences versus heterogeneous, Bayesian and momentum or nearest-neighbor traders), they estimate the informational efficiency of the market, i.e., trying to answer the question: "do prices fully reflect all available information?" What they find is that simple artificial intelligent agents can accurately infer and aggregate diverse pieces of information in many circumstances, and that they have difficulties in cases where human traders are also unable to determine the rational expectations equilibrium.

The link between micro decision level and macro outcome has also been carefully explored by Hoffmann et al. (2007). These authors describe the behavioral and cognitive attitudes of an investor at the micro level and explain their effects on decision making. A multi-agent based simulation is used to validate the model and to study the emergence of certain stock market phenomena at the macro level. The stock market is represented as a social network where information circulates randomly among heterogeneous investors. Under these hypotheses, they refine the main results of Dow theory.

A wealth of papers on financial markets were presented at the conference. In this special issue also, a large place is made to ABM of financial and credit markets. Biondi (2014) develops a very original theoretical analysis of share market price formation driven by accounting and market structures. Interacting heterogeneous investors are assumed to discover and process fundamental information disclosed by accounting system of share-issuing entity. Investors' information comes from market-driven signals (the price system) and firm specific (non-market) information (the accounting system). Both jointly drive the formation of aggregate share market prices through limited knowledge, chance and social interaction. Numerical simulations are provided under alternative accounting regimes (namely, historical cost and fair value accounting regimes), and help to better understand the occurrence of speculative bubbles and herd behavior. Another important contribution in this issue is the one of Grilli et al (2014) who focus on instability in financial systems and investigates the effect of credit linkages on macroeconomic activity. The paper analyzes the dynamics of the economy as a complex, adaptive and interactive system. In particular, it studies the impact of interbank connectivity on banks’ performances, bankruptcy waves and business cycle fluctuations. The agent based model allows to consider interbank link-
ages: it shows how strong interbank connections participate to the spread of the crisis through the network. A very recent article of Bargigli et al (2014) combines the ABM approach and the network ones to analyze the credit market.

4.3 The labor markets

The labor market is a major ingredient to any macroeconomic model but its working largely depends on micro phenomena. Understanding the way how micro and macro dimensions influence each other is a perfect goal for agent based modeling. As recalled by Neugart and Richiardi (2012), the roots of agent based labor market models must be traced back to two early macroeconomic ABM described above: Bergmann’s microsimulation of the US economy (Bergmann 1974) and Eliasson’s microsimulation of the Swedish economy (Eliasson 1976).

An early contribution specifically focusing on the labor market is Ballot (2002), which describes the functioning of the French labor market with its specific institutional rules. The paper points out in particular that firms have to be recognized as organizations: many of them have developed internal labor markets where social networks and interpersonal relations influence and are influenced by the way the firm is organized. Training, screening and incentives play a key role in the production process. Another original feature of the model is that the behavior of agents and the events they face depend partly on their past: the simulation model then reproduces the path dependency and the irreversibility of true dynamics. This model has recently been extended (Ballot et al. 2013) to investigate the workers trajectories, an essential phenomenon for understanding the labor market issues, and study labor market policies.

Another early contribution is Richiardi (2006), which builds an agent-based model of workers and firms, with on-the-job searching, endogenous entrepreneurial decisions and endogenous wage and income determination. The model is able to reproduce a number of stylized facts such as the Wage, Beveridge and Okun curve, and the skewness of wage, income and firm size distribution.

Another important contribution that ABM bring to the labour market analysis is the introduction of networks which provide channels for workers to find jobs. Search theory is presently the dominant paradigm but assumes randomness in the job finding process, an unsatisfactory black box. Some research (see for instance Pingle and Tesfatsion 2003, Thiriot et al. 2011) start to investigate this track, and the increase in empirical knowledge make it a worthwhile subject. Among the contributions to the conference, the
paper by Chen and co-authors (Chen and al. 2013) envisage matching on the labor market from a statistical physics perspective.

Finally, the spatial dimension is a very important feature of labor market and ABM can contribute to analyze its consequences as underlined in the contribution of Neugart to the conference (see also Dawid et al 2012).

5 Conclusion

The increasing popularity of ABM in different fields of economics corresponds to a change of perspective in the forma mentis of scientists. Traditional economy is based on a reductionistic approach according to which, if one knows the basic elements of a system, it is possible to predict its behavior and properties. ABM corresponds to a vision of socio-economic dynamics driven by interactions between heterogeneous actors: in that case, the knowledge of the individual parts is not sufficient to describe the global behavior of the structure.

The increase in computing power, the rise in influence of evolutionary ideas, and the financial crisis have provided the right blend of tools and incentives to develop further ABM. Contemporaneously, the importance of interactions in economics is being increasingly recognized as witnessed by the emergence of an economic literature on networks (see e.g Jackson 2007, Goyal 2009). Together with a better understanding of the relationships between ABMs and economic theory (Gintis 2007), this shall ascertain the status of ABMs as an adequate tool to investigate economic dynamics with heterogeneous interacting agents.

Still, calibration is a major challenge to be faced by ABM. Although ABM can use very eclectic data, calibration has remained until recently neglected by ABM modellers for various reasons such as the idea that the reproduction of realistic mechanisms (stylised facts) was enough to validate a theoretical model or the complexity of the task. However many tools have been used by other scientists and some can be derived from indirect inference methods invented by econometricians (Gouriéroux, Montfort, Renault, 1993) or Meta-modeling with a Krienging based approach (Salle I. and Yildizoglu, 2013), but these efforts are really first steps, and there is a need to design methods to validate jointly a model at the micro, meso and macro level.

Another important challenge relates to long-term dynamics. An evolutionary perspective demands that institutional evolution be, as well as growth, endogenously explained. Endogenous growth theory (see Aghion and Howitt, 2009) has provided some insights about what the appropriate

\footnote{Fagiolo, Moneta and Windrum (2007) review the many problems involved.}
institutions for growth are, depending on the distance to the technological frontier. Yet it encounters difficulties to make them endogenous. Similarly, institutions play a crucial role in ABM and so shall their evolution. As the models are flexible enough to formalize learning, it is possible to pursue a research agenda that aims at explaining the endogenous emergence of new institutions.

References


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