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Agent Based Models

A New Tool for Economic and Policy Analysis

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Are current economic models well equipped to provide useful policy prescriptions? Many economists would have certainly answered, "yes" before the recent Global Recession. This economic crisis has not only demonstrated the importance of banking and financial markets for the dynamics of real economies. It has also revealed the inadequacy of the dominant theoretical framework. Standard models have indeed failed to forecast the advent of the crisis. In addition, they have been unable to indicate a therapy able to restore economic growth.

Since the onset of the crisis, the discontent towards the dominant approach to economic modeling has flourished.[1] Criticism has been mainly directed towards the over-simplicity of standard models. Most features that have played a key role in generating the crisis, such as heterogeneity of agents, markets, and regulatory frameworks, financial innovation, securitization, are by and large overlooked by standard macro-models. A second kind of dissatisfaction is related to the hyper-rationality of individuals in standard models. Real markets (and financial markets in particular), are plenty of people acting on the basis of overconfidence, heterogeneous beliefs, imperfect knowledge of the states of the world, and of the consequence of humans' actions, etc. These features are not present in standard macro models, which typically build on the assumption of a representative individual knowing all the characteristics of the economy and able to replicate whatever human intelligence can do (Leijonhufvud, 1993). A third concern is the assumption of equilibrium. Standard models typically focus on states of the economy in which all markets clear. In contrast, the crisis has shown the possibility of situations in which some markets (and the market for labor in particular) do not clear. Standard models ignore the problems that would result from reactions of agents to such market disequilibria. They are therefore badly equipped to study how the economy behaves during crises.

1. Interestingly, this time critiques have not only come from "heterodox" schools of thought. They were also raised by more orthodox scholars, who made a significant use of the ingredients of standard models in the past (see e.g. Caballero, 2010, Krugman, 2009, Stiglitz, 2011). Moreover, the discussion about the adequacy of standard model has spread over the academia and it has also touched policy making authorities (see e.g. Trichet, 2010).

This note will provide a concise account of the current criticism towards standard models. At the same time, it will describe an alternative class of models, which has received increased attention in the recent years: Agent Based Models (ABMs). These new models characterize economic processes as dynamical systems of heterogeneous agents. The approach followed by ABMs is to a large extent opposite to the standard one. This is because heterogeneity, bounded rationality of agents and market disequilibria are explicitly taken into account. This feature alone makes these models a promising research tool for understanding the situations and problems emerged with the recent crisis.

The note is organized as follows. Section 1 briefly reviews the critiques raised towards standard models. Section 2 is devoted to present Agent Based Models, their strengths and limits vis-à-vis standard models. Section 3, contains a brief overview of the recent contributions to the analysis of macroeconomic policies in Agent Based Models. Finally, Section 4 concludes.

1. The case against standard macroeconomic models

Today most macroeconomic theories are microfounded, that is they are grounded on an account of what typical agents do and why they do it. Macroeconomic aggregates (such as GDP, unemployment) result from the decisions of the millions of individuals populating the economy. Thus, it seems quite reasonable to study the dynamics of those aggregates by starting from the characterization of the behavior of single agents at the microeconomic level. There is also another important motivation justifying the use of microfoundations in macroeconomics. The design of policies grounded on macroeconomic models not derived from first principles at the micro-level can be seriously flawed. This is because the reaction of agents to a given policy (e.g. lowering taxes) will change the parameters of the model used when the effects of the same policy were estimated. Thus without an understanding of such reactions, the desired results of a policy intervention can be invalidated[2].

The type of models that have become the standard today in macroeconomics[3] – namely the Dynamic Stochastic General Equilibrium Models (DSGEs) – faithfully adheres to the "microfoundations approach". This approach looks sound and uncontroversial, so at first glance no problem arises. However, the worries are related to the *type* of microfoundations adopted by DSGE models.[4] Let us start by briefly examine their main building blocks. First, DSGE models explain aggregate regularities in a "general equilibrium" framework, i.e. assuming that every market clears. Second, the behaviors of agents populating the economy are approximated via the introduction of a representative agent (Representative Agent Hypothesis, RAH), i.e. it is assumed that all agents in the economy are equal with respect to their preferences and characteristics.[5] Third, the choices of the representative agent are derived from a constrained

2. This is the essence of the famous « Lucas Critique » to earlier Keynesian general aggregative models, see Lucas (1976).

3. In what follows we shall use the term "DSGE Model" and "Standard Model", interchangeably.

4. This discussion of the criticism against standard models extensively builds on Stiglitz (2011). See also Caballero, (2010), Krugman, (2009), Kirman, (2010), Colander et al, (2009), and Leijonhufvud (2011) for other recent accounts of the fallacies of DSGE models in macroeconomics.

5. A more refined version of this assumption consist in the statement that only the first moments (i.e. the mean) of the distributions of agents preferences and characteristics matter at the macro level.

inter-temporal maximization problem, assuming that the agent has rational expectations (Rational Expectations Hypothesis, REH), i.e. assuming that he knows the true underlying model of the economy and that he makes an efficient use of all information available[6].

There are a number of reasons to believe that the above features make DSGE models badly equipped to investigate relevant economic issues, especially those emerged with the recent crisis. Consider for instance the provision of credit and the consequences of credit default and bankruptcy, i.e. elements that have been at the core of the causes of the crisis and of the diffusion of its adverse effects. The investigation of credit contracts needs to take into account the presence of information asymmetries between two distinct agents, the borrower and the lender. By assuming a representative agent the analysis of informational asymmetries is not possible.[7] Actually, even the credit markets are not conceivable (who is lending to whom?). As a consequence, there is no scope for credit default and bankruptcy. Likewise, the event of bankruptcy implies the distribution of losses among different actors (e.g. in the case of a bank, between depositors, shareholders and the state). How is it possible to account for these in a model if the actor is unique? [8]

More in general, the recent crisis has shown that *distributions matters*. One instance of this is the market for credit, where the distribution of information between borrowers and lenders plays a key role. However, the crisis and the associated surge in unemployment also generated sharp inequalities within the population: some individuals have seen their income falling either because they got unemployed or because of falling wages in a situation with depressed labor demand. Reduced incomes by a significant fraction of the population would normally lead to a fall in aggregate consumption (especially in presence of frozen credit markets). However, this cannot happen by assumption in a representative agent framework. Since the agent is at the same time worker and owner of the companies, what he gets less in terms of wages is compensated by what he gets in the form of higher profits of the company.[9]

Finally, many explanations of the emergence of the crisis have emphasized the role played by the wide inequalities that already existed before the crisis (see e.g. Fitoussi and Saraceno, 2010). All advanced countries have indeed been characterized by an increase in inequality in income and wealth since the 80s. In many countries (e.g. the US), such inequalities have not mapped into similar inequalities in consumption, thanks to the credit available to poor households (see e.g. Iacoviello, 2005, and Krueger and Perri, 2006). However, it is precisely the excessive indebtedness of the latter that ultimately originated the credit defaults triggering the crisis. Nevertheless, it is not possible to investigate the macroeconomic impact of different levels of inequality

6. Models belonging to the Real Business Cycle Tradition are surely pushing ahead for the most the foregoing synthesis. Nevertheless, it is also pursued by the core of the competing - and today more popular - New Keynesian theories of business fluctuations. Indeed, once the various frictions are let away, the New Keynesian "representative firm" still behaves like in a pure general equilibrium framework.

7. See also Kirman (1992) for a devastating account of the theoretical inconsistencies of the RAH.

8. Very recent works in the DSGE tradition however try to overcome the limits of the REH, and study the role of credit into models where some agents' heterogeneity is assumed (see e.g. Iacoviello, 2005, Campbell and Hercowitz, 2004, Berka and Zimmermann, 2011).

9. Another problem in standard models is represented by the assumption of homothetic preferences, i.e. the requirement that expenditure shares into different goods stay constant as income increases. In the real world, preferences are not homothetic. Accordingly, income distribution can influence both the level and the composition of final demand across different goods.

in DSGE models. By construction the RAH implies that only average income or wealth matter. The dispersion across individuals plays no role.

One possible objection to the above criticism is that any economic model is a highly stylized representation of reality and – besides the aforementioned cases – the RAH is still a useful trick to simplify matters in the analysis of other important issues wherein micro-heterogeneity is not relevant. Nevertheless, a good deal of recent empirical research on datasets at the microeconomic level (see e.g. Haltiwanger, 1997; Dosi, 2007, to cite only few of them) has revealed that heterogeneity matters in most cases. The presence of huge and persistent asymmetries has been found to be widespread across agents (e.g. among firms in employment, investment and in productivity levels). In addition, most of this micro-heterogeneity does survive aggregation. It turns out that, by sticking to the RAH, one loses the ability to investigate important aspects of reality which map from micro-heterogeneity to macro outcomes.

Besides the RAH, the assumption of rational expectations of agents (REH) constitutes another major weakness of DSGE models. Rational expectations presume that agents know the true underlying model of the economy and make an efficient use of the information they have. In addition, it requires that all agents must have the same (rational) expectation about a given variable.[10] These assumptions could sound conceptually reasonable to many. Indeed, why should individuals with a minimum sense of selfishness lose money by not exploiting as much as possible any piece information available to them? Nonetheless, a large evidence, especially in (but not limited to) financial markets (see e.g. Thaler, 2000, Schiller, 2001 to mention only few of them) has documented how expectations of agents are neither rational nor equal. Agents persistently make an inefficient use of information in the formation of their beliefs. More importantly, it is precisely the difference in beliefs that drives most of what occurs in financial markets (including the emergence of bubbles and crashes, see e.g. Hommes, 2006 and references therein). Besides this empirical evidence there is another more conceptual reason, that makes the REH problematic in light of the recent crisis. As we already mentioned, the REH implies that agents make an efficient use of the information available to them. However, it is the usefulness of available information, which looks severely undermined in the case of the recent crisis. The crisis has indeed been characterized by a major fall in the overall level of economic activity, not comparable to the small perturbations characterizing advanced economies before it. The response of the economic system to such a major shock can be quite different from the one to small fluctuations. It follows that the information gathered in the course of small perturbations can be hardly applicable to extrapolate an appropriate forecast for economic variables during the crisis. As Stiglitz (2011, pp. 602-603), candidly puts it:

> *"There hasn't been a crisis as deep as the current one for three-quarters of a century, so how can market participants form rational expectations about how modern economies respond to such a situation, unless they make the leap of faith that responses to a large crisis are similar to responses to smaller perturbations? […] Describing and analyzing the full rational expectations equilibrium is complicated enough; to presume that in*

10. Rational expectations are indeed an equilibrium concept applied to the context of agents' expectations. In this fashion, rational expectations have also a simplifying purpose similar to the RAH. Indeed, by assuming rational expectations, heterogeneity in expectations is washed away, which greatly simplify matters in several cases.

a rare event such as the current one that all economic and political actors have quickly gravitated to this equilibrium is beyond credence."

Furthermore, recent empirical works (e.g. Canning et al., 1998, Fagiolo et al., 2008, Castaldi and Dosi, 2009) have revealed that the distribution of aggregate output growth rates displays flat-tails. In practice, this means that the dynamics of advanced economies is characterized by small perturbations alternating with extreme growth events, which are more likely than what would be predicted by a normal distribution. It follows that extreme fluctuations (such as the recent crisis) are an inherent property of advanced economies, and thus their importance cannot be downplayed the rank of "black swan" or "outliers". Moreover, large fluctuations seem to be more related to errors and coordination failures of (heterogeneous) agents at the micro level, than to exogenous shocks at the macro level.[11] Models where one representative agent correctly anticipates the consequence of aggregate shocks (like DSGEs do) can hardly account for these extreme phenomena.

The general occurrence of extreme fluctuations at the macro level makes questionable another pillar of standard models, namely the hypothesis that all markets clear at any point in time. Indeed, large negative growth events (such as economic crises) are typically associated with situations of persistent unemployment, i.e. situations where one fundamental market – the market for labor – does not clear. By construction, models based on the market clearing assumption, cannot be used to analyze such situations. Furthermore, standard models often embed the presumption that the full employment equilibrium is also stable, i.e. that the economy naturally gravitates around such a state, being occasionally buffeted by exogenous shocks. This hypothesis is of little applicability in environments characterized by the presence of extreme fluctuations. Moreover, it can lead to fatal flaws in the design of policies. According to many (e.g. Stiglitz, 2011, Mishkin, 2011), monetary authorities overlooked the growing bubble in financial and housing markets partly because Standard Models where predicting that bubbles couldn't occur, and that was enough to focus the attention on inflation control to guarantee efficiency and growth.

2. Agent-Based Models and their structure

A natural way to follow in face of the problems exposed in the previous section would be departing from the representative agent paradigm, thereby introducing heterogeneity of agents' characteristics and behavior, and allowing for markets that do not clear. All the aforementioned characteristics add new degrees of complexity to macroeconomic analysis. As eloquently expressed by Tesfatsion (2006) :

"The modeler must now come to grips with challenging issues such as asymmetric information, strategic interaction, expectation formation on the basis of limited information, mutual learning, social norms, transaction costs, externalities, market power, predation, collusion, and the possibility of coordination failures."

Exploiting the growing capabilities of computers, Agent Based Models (ABMs) model economic processes as dynamic systems of heterogeneous interacting agents (Epstein and Axtell, 1996; Tesfatsion and Judd, 2006). In ABMs repeated interactions

11. According to Amendola and Gaffard (2011) the coordination failures arose in the course of the process of structural change which has characterized advanced economies are one of deep causes of the recent crisis.

among agents over time induce continuously changing microeconomic patterns, the aggregation of which generates a dynamics for the macroeconomic variable of interest (Pyka and Fagiolo, 2005).

Thus, in contrast to Standard Models, ABMs explicitly model agents' heterogeneity. Moreover, in ABMs each agent embodies less capability that the one required to let the entire system work. In other words, in ABMs agents do not know the "model" wherein they operate and therefore they do not have rational expectations. It is also important to stress that in ABMs is typically not imposed that interactions must occur at "equilibrium" (e.g. that transactions must occur only at equilibrium prices). This does not mean that equilibrium states cannot exist in ABMs and be eventually reached. The distinctive feature is instead that equilibria are true emergent properties of a far-from-equilibrium dynamics whose properties are explicitly analyzed and taken into account in the description of macroeconomic phenomena.[12] Moreover, in ABMs agents interact both through price as well as via non-price variables. Finally, market interactions are not mediated by a central authority (like in standard models), but it is local and occurs through a network of existing relationships across agents.[13]

The above ingredients represent a key advantage of ABMs compared to Standard Models. For instance, they allow one to explicitly accounts for phenomena such as asymmetric information between borrowers and lenders, inequality across agents, persistent unemployment, information diffusion, heterogeneous beliefs and the emergence of bubbles and crashes, financial contagion. As it was already discussed in the previous section, these are elements that have played a central role in the recent crisis.

ABMs have also another advantage that is more related to policy design, and is represented by their finer description of the economy compared to DSGE models. In modern economies very articulated and heterogeneous institutional arrangements often govern the functioning of key markets (e.g. labor and credit markets). The same macroeconomic policy can have different effects according to the different institutional setting in which it is implemented (Stiglitz, 2011). Institutional elements are typically excluded in DSGE models, whose results are derived in highly stylized frameworks. Baumol (2000 p. 231) discusses the perils of economic policies derived in such abstract settings:

> "As is suggested by the old Yiddish proverb […], 'for example' is not a proof.-*.[…] The proper first reply to the proverb is that 'for example' can certainly be a disproof. Illustrations can demonstrate conclusively that widely held beliefs, even some that have been derived rigorously from (rather oversimplified) models, are just not valid as general propositions. While things may sometimes work out as is usually believed, it is very possible and perhaps even very likely that outcomes will be entirely different. Thus the policy or behavior adopted on the basis of general belief can turn out to be counterproductive or even highly damaging"*

ABMs allow one to flexibly characterize various complex institutional arrangements, and to study their impact at the micro- and macroeconomic level. In the same respect, it is also possible to add to the model elements of real economic structures which

12. On these grounds ABMs follow the track initiated by previous disequilibrium models (e.g. Barro and Grossman, 1976, Amendola and Gaffard, 1998).

13. A more detailed and formal account of the basic structure of ABMs can be found in Pyka and Fagiolo (2005), Fagiolo and Roventini (2008).

policy-makers are more familiar with, thus improving the guidance of policy-making applied to particular contexts (see Dawid and Neugart, 2011 for a discussion of this point).

This finer-grained account of the economy does not come without costs. ABMs are typically more complex than standard models, and this implies that their analytical investigation is limited if not impossible. One must therefore employ computer simulations to analyze them. This raises a number of important issues such as: how get rid of the randomness present in any computer simulation exercise, and how to analyze and validate the results of the simulations. Another major challenge in ABMs lies in the choice of the rules agents follow to take their decisions. Indeed once the requirement of rationality and consistency of agents' choices (e.g. as it is implied by the REH) is let away one is left with many degrees of freedom in the design of agents' behavior. As a consequence, the model can be hardly falsifiable (a requirement that would be desirable for any theoretical model). Finally, the attempt to provide a finer description of economic dynamics can easily end up in over-complicated models, wherein causal relations are hard to grasp. Let us examine each of the above points in detail.

First, the randomness present in any economic series artificially generated through simulations can be easily circumvented through the application of standard Monte-Carlo procedures, already extensively applied in econometrics as well as in the analysis of standard models (e.g. Real Business Cycle models).[14] The problem of the specification of agents' behavioral rules is prima facie more complicated in the absence of some general principles underpinning agents' behavior (e.g. the one of perfect rationality). Two complementary solutions to this problem have gained momentum in the literature. The first one consists in designing agents' behavioral rules building on the evidence available from psychology experimental studies on human decision-making. This is also the way already paved by all theoretical studies which go under the label of "behavioral economics" (see e.g. Akerlof, 2002, Camerer et al., 2004, and reference therein). The other approach (see e.g. Dosi et al, 2010, Dawid et al, 2011) consists in selecting only those behavioral rules that are able to reproduce an ensemble of stylized facts at different levels of aggregation. More precisely, the model (i.e. the set of behavioral rules and their interaction structure) is "validated" only if it is able to *jointly* generate statistical properties that are characteristic of empirical data *both* at the macro level as well as at a a "meso" level of aggregation, i.e. at a level of aggregation that is intermediate between the micro and the macro, (i.e. involving industries or set of households). Requiring that a model is coherent with some statistical properties at the macro level should not surprise anyone, as it looks a necessary premise of any scientifically sound theoretical exercise. The novelty amounts to requiring that the model is also able to reproduce many properties that are observed at an intermediate level of aggregation (e.g. concerning distributions of firms characteristics, such as firm size and growth rates). Empirical studies (e.g. those mentioned in Section 2) have indeed produced a rich ensemble of stylized facts at the "meso" level. Imposing that such stylized facts must be reproduced by the model is a way of putting "empirical discipline" in the design of the model[15].

14. Practically speaking, many artificial series for a given macroeconomic variable are generated by holding fixed the set of parameters governing the behavior of agents and statistics that are relevant for the issue under analysis (e.g. average growth or volatility) are computed on each series. Each statistics is then averaged out in order to remove randomness.

One critique against ABMs, concerns the excessive number of parameters which enter in the specification of agents' behavioral rules. Many parameters in a model give a lot of freedom to the modeler, because in the end any possible stylized fact can be matched with the appropriate set of values for the parameters. Such models are therefore not falsifiable and should therefore be discarded. This criticism is similar to the one against basic polynomial data-fitting exercises: any set of data can be fitted with a polynomial of appropriate degree. In the case of ABMs it is possible to reply to this critique in two ways. First, it is true that ABMs in general feature more parameters than standard models. However, in ABMs it is not a matter of reproducing just one stylized fact but many at once! Indeed, the number of stylized facts that an ABM tries to reproduce (both at macro and meso level) is typically much larger than in a Standard Model, and this already puts a lot of constraints on the set of parameters' values that can be selected. Second, differently from polynomial data-fitting exercises, in ABMs it is required that parameters' values must be economically meaningful. Consider for example, the case of a parameter's value in a microeconomic investment decision rule allowing the replication of a stylized fact at the macroeconomic level but implying a crazy investment behavior at the firm level. This value would not be selected, precisely because it fails the requirement of being meaningful at the microeconomic level.

Finally, the critique that the complicated structure of ABMs can blur the causal mechanisms generating results seems to us a quite general remark applicable to any model, rather than a specific and unavoidable fallacy of ABMs. The "art" of economic modeling always involves a trade-off between realism and analytical simplicity and clarity. ABMs certainly privilege the former. Nevertheless, ABMs still are (and must remain) a stylized representation of economic reality. It is the therefore the ability of the modeler to design and analyze the model in such a way that the greater complexity involved by greater realism does not jeopardize the understanding of the mechanisms underlying certain economic processes.

It must also be stressed that - even in very complicated ABMs - causal mechanisms can be detected through counterfactual analyses. More precisely, the structure of ABMs often allow one to control the presence of some dynamics in the model (through an appropriate setting of the parameters), and to test how results are different when such dynamics are switched off/on. One can of course disapprove this procedure, by noting that counterfactual simulation analyses can never replace the generality and the precision of a theorem. This is certainly true. On the other hand, it must be acknowledged that economic theorems are many times derived on the grounds of heroic assumptions of little applicability in reality, and/or they are often limited to existence results about equilibria whose stability (e.g. the problem of whether and how an equilibrium is reached) is seldom investigated. Once again, it is a matter of making the right choice in the trade-off between simplicity and economic realism given the issue at hand. Moreover, one should consider the two approaches (computer simulations and analytical results) as possible complements rather than substitutes. [16]

15. This also goes in the direction of making economics a more empirically disciplined science. See also Stiglitz (2011) and Dosi (2004) for remarks on this point. It is also worth mentioning the standard models have been blamed of being unfalsifiable , precisely because a lack of such empirical discipline (see e.g. Fisher, 1989). Indeed, any observable situation can be interpreted in the terms of the theory that obeys to the first principles (such as inter-temporal optimization and rational expectations) by giving appropriate specifications to key variables (e.g. preferences), which are typically not observable.

3. Macroeconomic policies in Agent-Based Models: an overview of recent results

Several works in the recent years have tried to address macroeconomic policy issues using the ABM methodology. In what follows we try to provide an overview of these models, by classifying them into three policy areas: fiscal and monetary policies, bank regulation, and central bank independence.[17]

Fiscal and monetary policies

The Great Recession has renewed the interest for fiscal policies as an effective tool to tackle economic downturns. Dosi, Fagiolo, and Roventini (2010) analyze the role of fiscal policy in a two sectors ABM, bridging Keynesian theories of demand-generation and Schumpeterian theories of technology-fueled economic growth (the K+S model). A novel feature of this model lies in the analysis of both the short-run and long-run impact of fiscal policies. DSGE models embed a fundamental dichotomy about the effectiveness of policies. More precisely, the effects of fiscal and monetary policies on real variables are limited to the short-run, while in the long-run only supply-side policies can have real effects. This conclusion hinges upon the assumption that the economy gravitates around an equilibrium characterized by a structural (or "natural") level of unemployment where it always returns in the medium-run. However, if the economy is persistently away from this equilibrium, then the effects of fiscal and monetary policy can span over the short-run. By allowing the possibility of studying the behavior of economies that are persistently out of equilibrium, ABMs allow one to study under which circumstances fiscal policy has real effects also in the long-run. This model shows that the presence of a minimum level of redistributive fiscal policies is a necessary condition for economic growth. Without fiscal policy the economy gets stuck into a zero growth trajectory. In addition, the authors show the active fiscal policie can be sufficiently employed to reduce the volatility of the economy.

Russo, Catalano, Gallegati, Gaffeo, and Napoletano (2007) develop an ABM where a population of heterogeneous, boundedly rational firms and consumers/workers interact according to random matching protocols. The model delivers sustained growth characterized by fluctuations and reproduce micro and macro regularities such as the Beveridge, Phillips and Okun curves, firm growth-rate distributions, etc. On the policy side, they find that average output growth rate is non-monotonically linked to the tax rate levied on corporate profits if revenues are employed to finance R&D investment, whereas growth is negatively affected if the tax-revenues are employed to provide unemployment benefits.

DSGE models mostly deal with monetary policy, and searching for the best monetary rule. At the same time the current Great Recession has showed that monetary policy alone is not sufficient to put economies back on their steady growth path. Agent-based models can be employed to assess the effects and the limits of monetary policy, and to compare the ensuing results with policy prescriptions of DSGE models.

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16. It is also interesting to note that computer simulations have so far had much warmer welcome in other scientific disciplines (e.g. physics), where they are often employed as a complement to analytical investigations.
17. Due to space constraints we discuss only a selection of works in Agent Based Macroeconomics. For more extensive surveys of this literature see Tesfatsion and Judd (2006), Fagiolo and Roventini (2012), and Dawid, Fagiolo and Roventini (2012). The survey of this section builds on the last two.

Haber (2008) studies the impact of different fiscal and monetary policies under different expectation formation mechanism in an ABM characterized by the presence of households, firm, banks, a government and a central bank. The model is calibrated in order to produce "reasonable" time series for GDP, consumption, unemployment and the inflation rate. Next, positive fiscal (lower tax rate) and monetary shocks (higher money target) are introduced in the analysis. A central result of the paper is that both policies increase GDP growth, and inflation and reduce unemployment. The introduction of more sophisticated expectations of agents reduce the effects of fiscal policy, whereas it increases the impact of monetary policy. Dosi, Fagiolo, Napoletano, and Roventini (2011) extend the K+S model by adding a bank, which collects the deposits of firms, and provide costly loans to financially constrained firms on a pecking-order basis. The model is then employed to assess the effects of monetary policy in different income distribution scenarios. Simulation results show that higher income inequality increases the volatility of output, the unemployment rate and the likelihood of severe crises. The characteristics of income distribution affects the effectiveness of monetary policy: higher interest rates do not affect the dynamics of the economy up to an endogenous threshold – increasing in the level of economic inequality – above which the average growth rate of the economy falls and the amplitude of fluctuations, the unemployment rate and the probability of crises rise.

Finally, many central banks have largely adopted inflation targeting policies in the recent past, based on the belief that focusing on low inflation was enough to guarantee a good economic performance[18]. However, very few theoretical studies have tried to investigate the effects of higher or lower inflation on the dynamics of real aggregate variables. ABMs are well suited for the task because they allow one to study how different inflation rates impact on the functioning of the mechanisms of exchange into an economy. Ahsraf and Howitt (2008) study the effects of inflation on real activity by extending the ABM model developed in Howitt and Clower (1998). In the model boundedly rational agents trade several goods, and specialized traders mediate exchange. In this framework, high inflation rates lead to lower mean GDP growth and to higher GDP volatility. The reason is that higher mean inflation is also associated with higher dispersion of prices. In turn, higher price dispersion induces more volatility in the demand faced by single traders, with the consequence that the rate of bankruptcy of traders is increased. Bankruptcy can have large effects in this model. This is because the failure of few traders affects also the exchange patterns of other traders in the system and let them to fail as well. The consequence is that the functioning of the whole mechanism of exchange in the economy is altered when the inflation rate is high.

Bank regulation

The flexibility of ABMs is extremely useful to test the impact of different regulation frameworks on banks' behavior. For instance, one can assess how different regulations affect the liquidity of the interbank payment system or how alternative micro-prudential rules impact on macroeconomic stability. The latter issue is investigated in Ashraf, Gershman, and Howitt (2011). They build an ABM wherein heterogeneous firms inte-

18. Howitt (2011) contains for a very recent evaluation of the interplay between central bank practices and theory, and a discussion of the usefulness of ABMs for the conduct of monetary policy.

ract with banks providing them credit. Banks are subject to various regulations, such as capital adequacy ratio and limits to loan-to-value ratios. Simulations of the model show that: i) the economy can be hit by "rare disasters", where the behavior of banks strongly affect macroeconomic performance; ii) during a crisis, higher loan-to-value ratios and lower capital-adequacy ratios allow the economy to recover faster; iii) banks can be an important "financial stabilizer" of the economy, easing the entry of new firms and avoiding the incumbents to go bankrupt. Raberto, Teglio, and Cincotti (2010) find that lower capital adequacy ratios can spur growth in the short-run, but the higher stock of private debt can lead to higher firm bankruptcies, credit rationing and serious economic downturns.

Also the network structure between firms and banks can play a significant role in determining the emergence, the depth and the diffusion of a crisis. Delli Gatti, Gallegati, Greenwald, Russo, and Stiglitz (2010) develop an ABM populated by banks and financially constrained firms to study the properties of a "network-based" financial accelerator. The topology of the network is continuously evolving because firms can switch their partner, in order to find better credit conditions (i.e. lower interest rates). Simulation results show that the interactions of financially constrained agents, occurring through the evolving credit network, give rise to business cycles and to financial crises. Hence, policy makers can try to reduce the magnifying effect of the network-based financial accelerator by changing the network structure. On a related ground, Battiston, Delli Gatti, Gallegati, Stiglitz and Greenwald (2009) show the possibility of a non-monotonic relation between the degree of connectivity of a financial network (measured by the average number of connections of each agent in the network) and the likelihood of systemic crises. When the network is poorly connected, increasing the number of connections lowers systemic risk, because it widens the possibility of diversifying idiosyncratic shocks. In contrast, when the network is already dense (i.e. average degree is high), increasing the number of connections has adverse effects. This is because the risk diversification effect is overwhelmed by the "contagion effect", i.e. the fact that everybody in the system is increasingly exposed to everybody else's shocks. As a consequence of that, the dynamics of agents' balance sheets become strongly correlated, and this leaves open the possibility that small shocks may trigger systemic crises.

Galbiati and Soramaki (2011) use an ABM in order to assess the efficiency of alternative interbank payment systems. Heterogeneous banks choose their (costly) liquidity stock at the beginning of the day in order to satisfy an exogenous random stream of payment orders. If some banks exhaust their liquidity stock, they must delay their payments until new liquidity arrives from other banks possibly leading to the gridlock of the system. The model shows that the efficiency of the payment system increases if the number of banks is small and if they are encouraged to provide more liquidity. Moreover, there are strong economies of scale in payment activity (higher volumes reduce total payment costs).

Central bank independence

ABMs have also been employed to study political economy issues related to the institutional role of central banks and to the way monetary policy is announced to the public. Rapaport, Levi-Faur, and Miodownik (2009) study why during the nineties many governments decided to delegate authority to their central banks, by employing an ABM where heterogeneous countries decide whether to introduce central bank independence taking into account the behavior of their neighbors. Simulation results, conducted under a Monte Carlo exploration of the parameter space, show that the emergence and the rate of adoption of central bank independence is positively related to the size of the zone of influence of neighboring countries.

The time-inconsistency problem faced by central banks is analyzed in a more general framework by Arifovic, Dawid, Deissenberg, and Kostyshyna (2010) using an ABM where the interaction between a boundedly-rational central bank and a population of heterogeneous agents determines the actual inflation rate. The agents can either believe the inflation rate announced by the central bank or employ an adaptive learning scheme to forecast future inflation. Computer simulations of this model show that the central bank learns to sustain an equilibrium with a positive, but fluctuating fraction of "believers", and that this outcome is Pareto superior to the equilibrium determined by standard models.

4. Conclusions

In this note we have provided a brief account of the status of macroeconomic theory and policy in light of the recent economic crisis. The Great Recession has revealed the inadequacy of the current standard models in macroeconomics to analyze economic crises and to provide useful policy prescriptions to restore growth and employment. This inadequacy of standard models stems from the type of approach followed to describe the behavior of agents at the microeconomic level. In particular, three cornerstones of this approach have come under question: i) the use of the representative agent to approximate the behavior of the individuals populating the economy; ii) the assumption that agents form rational expectations when forecasting economic variables; iii) the assumption that all markets clear. In contrast the recent economic events seem to be better described by models featuring boundedly rational heterogeneous agents and wherein markets do not necessarily clear at all times. Agent Based Models (ABMs) are a new class of models that embed all the above features, and therefore qualify as a promising alternative to standard models. In this note, we have described the basic structure of these models, their pros viz. standard models. We have also, discussed the problems one finds in the construction and analysis of ABMs and the solutions that so far have been proposed to deal with them. Besides, the possibility of getting rid of the drawbacks of standard models, another interesting feature of ABMs is the possibility of using them as computational laboratories to analyze policies under the different institutional contexts that are observed in reality. This is typically precluded in simple analytical models. Although the latter models can be useful in a number of situations (provided that one introduces heterogeneity, bounded rationality and the possibility of disequilibrium in the picture), the possibility of conducting finer-grained analysis of policies under more realistic conditions should be considered a strong added value of Agent Based Models.

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