Economic Modelling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/econmod

# No man is an Island: The impact of heterogeneity and local interactions on macroeconomic dynamics

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ARTICLE INFO

*JEL classification:*
E03
E32
E37

*Keywords:*
Agent-based model
Local interactions
Heterogeneous agents
DSGE model

ABSTRACT

We develop an agent-based model in which heterogeneous firms and households interact in labor and good markets according to centralized or decentralized search and matching protocols. As the model has a deterministic backbone and a full-employment equilibrium, it can be directly compared to Dynamic Stochastic General Equilibrium (DSGE) models. We study the effects of negative productivity shocks by way of impulse-response functions (IRF). Simulation results show that when search and matching are centralized, the economy is always able to return to the full-employment equilibrium and IRFs are similar to those generated by DSGE models. However, when search and matching are local, coordination failures emerge and the economy persistently deviates from full-employment. Moreover, agents display persistent heterogeneity. Our results suggest that macroeconomic models should explicitly account for agents' heterogeneity and direct interactions. Moreover, our results point to the role of quantity adjustments in determining the ability of the economy to return or not to full-employment.

## 1. Introduction

In this work, we develop a small-scale agent-based model to study the macroeconomic outcomes (e.g. full-employment, coordination failures, involuntary unemployment) emerging out of the interactions occurring between heterogeneous firms and households in good and labor markets.

Following the "New Classical" revolution, most macroeconomists have been developing micro-founded macroeconomic models where a fully rational, representative household or firm maximizes an intertemporal utility or profit function under some constraints. Such a methodological commitment has allowed the profession to circumvent the problems of existence and stability of the general equilibrium (Kirman, 1989). Nevertheless, the price paid for such a shortcut has not been cheap: agents' heterogeneity and local interactions have been disregarded (see Kirman, 1992, for a sharp critique of the representative agent assumption).

At the same time, since the seminal contribution of Leijonhufvud (1970), a contrasting research venture has been studying how coordination mechanisms in decentralized markets can possibly lead to full-employment equilibrium or to persistent disequilibria (see e.g. Solow and Stiglitz, 1968; Clower and Leijonhufvud, 1975). In the latter case, mismatches between demand and supply of goods and labor are the norm, coordination failures (Cooper and John, 1988) and involuntary unemployment can endogenously arise.

The natural outcome of such a program is to consider the economy as a *complex evolving system*, i.e. as an ecology populated by heterogeneous agents whose far-from-equilibrium interactions continuously change the structure of the system (Farmer and Foley, 2009; Kirman, 2010, 2016; Rosser, 2011; Dosi, 2012; Battiston et al., 2016). This is the methodological core of agent-based computational economics (ACE, Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008). Agent-based models (ABM) have "behavioral" microfoundations (Akerlof, 2002): in line with the micro-empirical evidence, agents (e.g. firms, workers, households) behave adaptively and employ heuristics in their decision and forecasting processes (see e.g. Tversky and Kahneman, 1986; Gigerenzer and Brighton, 2009; Camerer et al., 2011; Gigerenzer and Goldstein, 2011; Hommes, 2014).

Agent-based models have received increasing attention after the Great Recession, and policy makers have called for a plurality of methods (see e.g. Trichet, 2010; Haldane, 2016). According to the former president of the European Central Bank, Jean-Claude Trichet (2010):

> *The key lesson I would draw from our experience is the danger of relying on a single tool, methodology or paradigm. Policy-makers need to have input from various theoretical perspectives and from a*

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http://dx.doi.org/10.1016/j.econmod.2017.05.004
Received 31 May 2016; Received in revised form 22 April 2017; Accepted 9 May 2017
0264-9993/ 

*range of empirical approaches. Open debate and a diversity of views must be cultivated [...] First we need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. Agent-based modelling dispenses with the optimization assumption and allows for more complex interactions between agents. [...] Second, we may need to consider a richer characterization of expectation formation. Rational expectations theory has brought macroeconomic analysis a long way over the past four decades. But there is a clear need to re-examine this assumption [...] Third, we need to better integrate the crucial role played by the financial system into our macroeconomic models.*

As agent-based models[1] have taken a different methodological and theoretical perspective with respect to DSGE models, a comparison between the two different approaches is needed.[2] This is the aim of the present work, where we develop a parsimonious[3] model which bridges the agent-based framework with the DSGE one (see Fagiolo and Roventini, 2012, 2017, for a comparison of the DSGE and ACE paradigms).

The first set of research questions we explore with our model are: (i) the extent to which DSGE and agent-based models are different and, related to that, (ii) the identification of the fundamental mechanisms that allow one to move from one perspective to the other. This is possible as our ABM is — similarly to DSGE models — characterized by the presence of a full-employment homogeneous-agents equilibrium, which can be considered as the reference point for the dynamics of the economic system. Moreover, as in a DSGE framework, the model sports a deterministic skeleton that can be hit by exogenous stochastic shocks. Such a structure allows one to directly compare the impulse-response functions (IRF) produced by both models and to assess the conditions (if any) under which the economy goes back to the full-employment equilibrium after a shock.

The second set of research questions that we explore relates to the understanding of: (i) the possible emergence of coordination failures out of the interactions of agents in the goods and labor markets, and (ii) the role of real wage flexibility as a coordination mechanism to restore the full-employment equilibrium.

In the model, market interactions among (possibly) heterogeneous firms and households occur according to two different protocols. Similarly to DSGE models, in the *centralized matching scenario*, a fictitious auctioneer solves any possible coordination problem among the agents. On the contrary, in the *decentralized matching scenario*, agents locally interact in the markets. In such a regime, matching frictions and agents' heterogeneity may lead to imperfect allocations of goods and labor.

In both scenarios, we study the response of the economy to negative productivity shocks. Simulation results show that in the fully centralized scenario, the economy always come back to the full-employment equilibrium, thus exhibiting a dynamics consistent with standard DSGE models. The presence of a "benevolent social planner" that organizes information efficiently works as a deus ex machina, thus solving any possible coordination issue among agents. On the contrary, in the fully decentralized regime, where information is dispersed and interactions are local, the economy fluctuates around an underemployment equilibrium characterized by persistent heterogeneity in firm and household populations. In addition, real wage movements are not able to drive the economy back to the full-employment equilibrium. The latter results depends on the interplay between demand feedbacks and matching frictions in a population of heterogeneous agents.

Our results suggest that macroeconomic models should seriously take into account agents' heterogeneity and decentralized market interactions. They also highlight the importance of quantity adjustment mechanisms (more than price adjustments) in determining the ability of the economy to keep full-employment.

The rest of the work is organized as follows. In Section 2, the model is introduced. Simulation results are presented in Section 3. Finally, Section 4 concludes.

## 2. The model

We consider a closed economy populated by $F$ firms and $H$ households. Firms produce a consumption good by using a linear technology that employs only labor. Households supply labor inelastically and consume the final good using the wage received by firms and their stock of liquid wealth. In the good and labor markets, firms and households are matched according to different protocols. The model is stock-flow consistent (SFC, see e.g. Godley and Lavoie, 2012): the transaction flow matrix is reported in Appendix A.

### 2.1. Timeline of events

In any given time period ($t$), the following microeconomic decisions take place in sequential order:

1. Financial state variables are updated. Firms update their net-worth and households update their wealth.
2. Firms set their offered wage, the selling price and determine their expected demand.
3. Households compute their desired consumption levels.
4. The labor market opens. Employers and employees are matched using different protocols (see Section 2.3.1 below). Production takes place. Households receive their wages.
5. The goods market opens. Firms and consumers are matched using different protocols (see Section 2.3.2 below). Firms compute their profits and distribute dividends to households.
6. Households calculate their consumption expenditure and their savings.
7. Bankrupted firms exit from the economy and are replaced by new ones on a one-to-one basis. The wealth of defaulted households is reset to a constant value.

At the end of each time step, aggregate variables (e.g. GDP, investment, employment) are computed summing over the corresponding microeconomic variables.

### 2.2. Consumption, production, prices and wages

Firms fix production as well as the price and wage they offer to the workers. At the same time, households set their desired consumption.

In line with the spirit of agent-based models and with microeconomic evidence, agents have adaptive behaviors and employ heuristics (see e.g. Tversky and Kahneman, 1986; Gigerenzer and Brighton, 2009; Camerer et al., 2011; Gigerenzer and Goldstein, 2011; Hommes, 2014), which usually boil down to linear decision rules. This also allows to keep the dimensionality of the parameter space as low as possible. Each decision rule is a linear combination of two effects: (i) a *within*' effect reflecting decisions based on the past levels of agent's state variables; (ii) a *network* effect accounting for the position of each agent with respect to its own peers. The latter effect allows to study how social interactions with neighbors (see Brock and Durlauf, 2001; Durlauf, 2004) influence the decisions of each agent.

[1] The number of macroeconomic agent-based model is increasing fast and an exhaustive list is beyond the scope of this work. For germane macro ABMs, see Russo et al. (2007), Dosi et al. (2010, 2013, 2015, 2016), Lamperti et al. (2016), Delli Gatti et al. (2010), Ashraf et al. (2011), Dawid et al. (2014), Riccetti et al. (2015), Assenza et al. (2015), Popoyan et al. (2015), Seppecher and Salle (2015). See also Fagiolo and Roventini (2012, 2017) for a survey of macro agent-based models.

[2] Other works have instead tried to introduce bytes of heterogeneity in standard DSGE models, see e.g. De Grauwe (2012), De Grauwe and Macchiarelli (2015), Assenza et al. (2014), Guerini (2013), Violante et al. (2015), Dilaver et al. (2016) and Agliari et al. (2017).

[3] Our model has a leaner structure than other macroeconomic agent-based models and most medium-scale DSGE models, as it contains a relatively low number of equations and parameters. In addition, it allows the direct computation of one equilibrium (the full-employment one) which enhances comparison with the DSGE frameworks.