An Agent Based Decentralized Matching Macroeconomic Model

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Abstract

In this paper we present a macroeconomic microfounded framework with heterogeneous agents – individuals, firms, banks – which interact through a decentralized matching process presenting common features across four markets – goods, labor, credit and deposit. We study the dynamics of the model by means of computer simulation. Some macroeconomic properties emerge such as endogenous business cycles, nominal GDP growth, unemployment rate fluctuations, the Phillips curve, leverage cycles and credit constraints, bank defaults and financial instability, and the importance of government as an acyclical sector which stabilize the economy. The model highlights that even extended crises can endogenously emerge. In these cases, the system may remain trapped in a large unemployment status, without the possibility to quickly recover unless an exogenous intervention.

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1 Introduction

In recent years many economists have developed agent-based models to investigate the working of a macroeconomic system composed of heterogeneous interacting entities (Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008). In general, the idea is to start from simple (adaptive) individual behavioral rules and interaction mechanisms and to simulate a model in order to reproduce the emergence of aggregate regularities and endogenous crises. In a sense, this is a generative approach according to which we construct the macroeconomy from the "bottom-up" (Epstein and Axtell, 1996). In what follows, we report some examples of agent-based models showing emergent macroeconomic features based on the interplay between two fundamental characteristics of agent-based models: *heterogeneity* and *interaction*. We also provide a discussion on early contributions, particularly in the field of microsimulation, which provided the bases for future developments of heterogeneous interacting agent models. Moreover, we describe the possible use of the agent-based methodology in order to assess the role of different economic policies.

One of the basic characteristics of agent-based models is *heterogeneity*. Agents may differ in many dimensions such as income, wealth, size, financial fragility, location, information, and so on. One of the main advantages of considering agent heterogeneity is that aggregate regularities are not approximated by the behavior of a "representative agent" (Kirman, 1992; see also Gallegati and Kirman, 1999). The latter assumption, indeed, may lead to some inconsistencies, for instance because real-world data are often not Gaussian distributed, showing in many cases a *power law* shape. Consequently, it is usually not possible to reduce the complexity of macroeconomic dynamics to the behavior of a single agent with an "average" behavior, because the average does not represent the behavior of the system. As a consequence, macroeconomic models based on the representative agent hypothesis suffer from a "fallacy of composition". However, even in mainstream economic models it is possible to introduce a certain degree of heterogeneity. For instance, the recent debate in the DSGE (Dynamic Stochastic General Equilibrium) models community is focused on the introduction of financial factors and agents' heterogeneity. However, another basic feature that can be hardly introduced in mainstream models and that is instead at the root of agent-based models is the "direct interaction" among heterogeneous agents.

As for the specific topic regarding the *interaction* among agents, earlier contributions are based on a stochastic approach. Even in the case of stochastic interaction among individual agents, aggregate regularities may emerge. Indeed, the aggregation of simple interactions at the micro level can generate sophisticated behavior at the macro level. An early contribution on this topic is the one proposed by Föllmer (1974): he studies the dynamics of an exchange economy with random preferences. By applying the physics tools from interacting particle systems, Föllmer (1974) shows that even weak interaction may propagate through the economy and give rise to aggregate uncertainty causing large price movements and even a breakdown of price equilibria. Kirman (1991, 1993) proposes an analysis of the effects of local interactions in an exchange model with fundamentalists and chartists; in particular, Kirman (1993) provides an interesting analogy between biology and economics, focusing on the similarities between the behavior of ants and the dynamics of financial markets. See Brock (1993) and Kirman (1999) for a review of models with interacting agents. See also the reviews proposed by Gallegati and Kirman (1999) and Delli Gatti et al. (2000).

However, agent-based macro modelling has a 50 years tradition and at least a seminal paper can be cited, that is Orcutt (1957), which founded the microsimulation approach. "Microsimulation is a methodology used in a large variety of scientific fields to simulate the states and behaviors of different *units* – e.g. individuals, households, firms – as they evolve in a given *environment* – a market, a state, an institution. [...] Compared to other methodologies based on representative agents or aggregate level analysis, e.g. computable general equilibrium or macroeconomic models, the main strength of [microsimulation] is indeed to simulate how a certain policy change may differently affect heterogeneous individuals (or other entities). Furthermore, modeling at the micro level allows macro phenomena to emerge "from the bottom up" without the aggregation bias deriving from the use of statistical average" (Baroni and Richiardi, 2007, p. 2). Further developments of such a model led to the dynamic microsimulation model DYNASIM (Wertheimer et al., 1986). For a comprehensive review of microsimulation studies, see Baroni and Richiardi (2007).

Two (independently developed) contributions in which the foundations of "bottom up" macroeconomics based on boundedly rational agents can be traced back to the microsimulation approach, are those proposed by Bergmann (1974) – see also Bennett and Bergmann, 1986 –, and Eliasson (1977) – see also Eliasson, 1984). Indeed, Neugart and Richiardi (2012, p. 3), which refer in particular to the analysis of the labor market, maintain that the roots of agent-based models (ABMs) "must be traced back to two early studies that are generally not even recognized as belonging to the AB tradition: Barbara Bergmann's microsimulation of the US economy (Bergmann, 1974) and Gunnar Eliasson's microsimulation of the Swedish economy (Eliasson, 1976)".

The "transactions model" by Bergmann (1974) is a development of Orcutt's microsimulation approach, in which the behavior of individual agents is based on decision rules, rather than consisting of transition probabilities from one state to another. As noted by Neugart and Richiardi (2012, p. 8), "in the early 1974 version, only one bank, one financial intermediary and six firms, 'representative' of six different types of industrial sectors / consumer goods (motor vehicles, other durables, nondurables, services and construction) are simulated. In the labor market, firms willing to hire make offers to particular workers, some of which are accepted; some vacancies remain unfilled, with the vacancy rate affecting the wage setting mechanism. Unfortunately, the details of the search process are described only in a technical paper that is not easily available anymore (Bergmann, 1973). Admittedly, the model was defined by Bermann herself as a 'work in progress', and was completed only years later

(Bennett and Bergmann, 1986)".

The "micro-to-macro" model by Eliasson (1976), which we can also refer to as MOSES ("Model of the Swedish Economy") is a dynamic microsimulation model in which firms and workers are the basic unit of analysis. While a concise description can be found in Eliasson (1977), a developed version of such a model is that proposed in Eliasson (1991). MOSES is particularly suited for analyzing industrial growth; therefore, manufacturing is the most detailed sector in the model. The manufacturing sector is divided into four industries/markets (raw materials, processing, semi-manufacturing, durable goods manufacturing), and the manufacturing of consumer nondurables. In particular, the manufacturing sector is populated by 225 firms, a bank, the government, an exogenous foreign sector; then, there are an entry-exit process and the markets replacing mechanical input-output coefficients between selling and buying firms.[1] In such an experimentally organized market environment, competition does not lead to a "competitive equilibrium". Indeed, the MOSES model considers Smithian competition, involving rivalry and an entry-exit process related to innovation dynamics. According to Eliasson (1991), this creates a continuous state of disequilibrium, leads to economic growth, and generates systematic divergences between *ex ante* plans and *ex post* realizations, providing a synthesis of Schumpeterian and Wicksellian ideas in the spirit of the Stockholm School.

The MOSES model has been used to study the characteristics of both business fluctuations and endogenous growth.[2] This model also has assumptions about money and credit. Although the interest rate is set exogenously, it can depend on firms' risk and credit rationing. Moreover, the framework has been extended to include venture capital by capitalists of heterogeneous competence as a source of economic growth (Ballot et al., 2006). However, the model does not have multiple banks; consequently, bank failures are not considered. Moreover, the model does not consider the equity market.

During the 1990s, the MOSES model has been further extended in order to better analyze some economic growth issues such as the effects of many types of endogenous technical progress, the process of learning by doing, the introduction of incremental and radical innovations based on R&D and "human capital" investments, and the role of incremental and radical imitations. These features yield endogenous waves of innovation but also the possibility of extended "lock-in" periods (Ballot and Taymaz, 1998). A recent extension with 16 countries shows that the combination of endogenous competencies and spillovers can reproduce "club convergence" and "global divergence".

[1] The boundedly rational rules which guide agent behavior are based on a 5 year period of interviews with large US firms and have been formalized in a book (Eliasson, 1976).

[2] Moreover, the model shows (see Eliasson, 1985, p.78-83) emergent non-trivial phenomena such as the fact that a fast stabilization of prices is detrimental to macroeconomics stability, that structural diversity makes the economy more stable against shocks and lowers growth losses, and that entry is a central feature in an innovative economy.

Finally, a central feature of the MOSES model is that major costs of macroeconomic growth are due to agents' mistaken plans which generate non-linear dynamics and path-dependent trajectories. Consequently, model simulations may exhibit an unpredictable and disorderly behavior. According to Eliasson (1991), this means that the *complexity* of such a model, although less complex than reality, prevents the external observer from predicting the behavior of the economic system. This also holds for policy makers which should behave quite cautiously, so to avoid to do more harm than good through policy interventions. We will provide a comparison between some aspects of this model and some characteristics of the one we propose in the present paper.

Let's now discuss some other recent contributions in the field of agent-based computational economics, with a particular emphasis on the analysis of macroeconomic dynamics. Howitt and Clower (2000) show that economic organization may emerge from the bottom-up through decentralized interactions. Fagiolo et al. (2004) investigate labor market dynamics and the evolution of aggregate output. In particular, they model a decentralized matching process to describe the interaction between workers and firms in context characterized by endogenous price formation and stochastic technical progress. Delli Gatti et al. (2005) show that the interaction of financially fragile firms generates power law distributions and may lead to large crises. Along these lines, Delli Gatti et al. (2009, 2010) analyze the role of financial factors in a credit network economy in which even small shocks may lead to bankruptcy avalanches. Russo et al. (2007) present an agent-based model in which bounded rational firms and workers interact on fully decentralized markets both for final goods and labor. The model is used to analyze the role of fiscal policy in promoting R&D investments that may increase economic growth. This model has been further developed by Gaffeo et al. (2008) through the introduction of a similar matching protocol for the credit market. Haber (2008) investigates the effects of fiscal and monetary policies in a macroeconomic framework. Westerhoff (2008) analyzes the role of regulatory policies on financial markets. Neugart (2008) evaluates the role of labor market policies. Deissenberg et al. (2008) provide a massively parallel agent-based model, named EURACE, which they use to simulate the European economy. Based on the EURACE framework, Cincotti et al. (2010) investigate the interplay between monetary aggregates and the dynamics of output and prices by considering both the credit extended by commercial banks and the money supply created by the central bank. In particular, they study the effects of quantitative easing as a monetary policy. Building upon Dosi et al (2006, 2010), Dosi et al. (2012) analyze the interplay between income distribution and economic policies. They find that more unequal economies are exposed to more severe business cycles fluctuations, higher unemployment rates, and higher probability of crises. They also find that fiscal policies dampen business cycles, reduce unemployment and the likelihood of large crises, and may affect positively long-term growth. Westerhoff and Franke (2012) analyze the effectiveness of various stabilization policies, so using the agent-based approach for economic policy design. Hence, agents-based macroeconomic models show that an alternative formulation of microfoundations is possible for complex environment and this has relevant implications for policy advice (Dawid and Neugart, 2011). Fagiolo and Roventini (2009, 2012) review both methodological and policy-oriented papers employing agent-based simulation techniques.

Our aim is to develop a macroeconomic framework with heterogeneous agents that interact through a decentralized matching process presenting common features across markets. The framework is basic since we propose a minimal macroeconomic model and it is flexible because this baseline setup is thought to be enriched by adding new modules with different agents, markets, and institutions. Indeed, in this paper we propose an agent-based macroeconomic model in which there are three classes of computational agents - individuals, firms, banks - interacting in four markets - goods, labor, credit and deposit - according to a fully decentralized matching mechanism. Moreover, we build a model in which stocks and flows are mutually consistent. Stock-flow consistency is a very important feature (Godley and Lavoie, 2006) that economists are applying also in the field of agent-based macroeconomics as, for instance, in Cincotti et al. (2010, 2012), Kinsella et al. (2011), Seppecher (2012).

This paper is just a first step towards a complex task that is the development of a microfounded general (dis)equilibrium macroeconomic model based on heterogeneous interacting agents. Although the model is populated by many heterogeneous agents which interact in a truly decentralized way in different markets, various features of a macroeconomic framework have still to be introduced, for instance technological progress, human capital, the foreign sector, etc. For these reasons, it is quite difficult to compare our result with those emerging from other models which instead include long-run growth factors, as for instance the previously discussed MOSES model. Moreover, our model is much more focused on the relationship between financial factors and the real economy, considering the possibility of firm and bank defaults. In our framework, indeed, even small shocks can lead to large fluctuations due to financial contagion. Thus we focus on some characteristics such as the dynamics of financial variables – firms' leverage, banks' exposure – and their interplay with the business cycle. Indeed, many papers recently try to understand the leverage process both for firms and banks: Adrian and Shin (2008, 2009, 2010), Brunnermeier and Pedersen (2009), Flannery (1994), Fostel and Geanakoplos (2008), Greenlaw, Hatzius, Kashyap and Shin (2008), He, Khang and Krishnamurthy (2010), Kalemli-Ozcan et al. (2011).[3] Geanakoplos (2010) finds that leverage is pro-cyclical, while Kalemli-Ozcan et al. (2011), as well as Adrian and Shin

[3] Although the word "exposure" is usually used in a credit risk context (for instance the exposure at default – EAD – in Basel II agreement), here it exactly refers to the ratio between corporate credit and equity, which is different to the asset/equity ratio, given that in the balance sheet there are also assets which are supposed to be *risk free*: government bonds and, in the case of mismatches, residual cash. In addition, according to the Basel II framework, all our corporate credits have EAD equal to 1 (especially under the "foundation approach") then the overall bank EAD is just the sum of the extended corporate loans. For these reasons, we think that the word "exposure" is more appropriate compared to other words (such as "leverage", that could be a better choice for the asset/equity ratio).

(2008, 2009), find that the leverage pattern for non-financial firms is acyclical (instead this is pro-cyclical for investment banks and large commercial banks).

The leverage level is a component of a more general discussion on firm and bank capital structure, such as in Booth et al. (2001), Diamond and Rajan (2000), Gropp and Heider (2010), Lemmon, Roberts and Zender (2008), Rajan and Zingales (1995). In the economic literature there are many theories on capital structure but almost all previous papers in the agent-based macroeconomic approach assumed a "pecking order" theory (Donaldson, 1961; Myers and Majluf, 1984), based on information asymmetry, according to which investments are financed first with internally generated funds, then with debt if internal funds are not enough, and equity is used as a last resort. A different perspective on the firms' financial structure was proposed by the "trade-off" theory, firstly observed in a paper concerning asset substitution (Jensen and Meckling, 1976), and in a work on underinvestment (Myers, 1977). This theory is based on the trade-off between the costs and benefits of debt and implies that firms select a target debt-equity ratio. The empirical literature found at first contrasting evidence to support these theories. Then, a refined version of the trade-off theory was proposed: the "dynamic trade-off theory" (Flannery and Rangan, 2006). In this theory firms actively pursue target debt ratios even though market frictions temper the speed of adjustment. In other words, firms have long-run leverage targets, but they do not immediately reach them, instead they adjust to them during some periods. Dynamic trade-off seems to be able to overcome some puzzles related to the other theories, explaining the stylized facts emerging from the empirical analysis and numerous papers conclude that it dominates alternative hypotheses: Hovakimian, Opler, and Titman (2001), Mehotra, Mikkelsen, and Partch (2003), Frank and Goyal (2008), Flannery and Rangan (2006). Moreover, Graham and Harvey (2001) conduct a survey where they evidence that 81% of firms affirm to consider a target debt ratio or range when making their debt decisions.

Then, one of the major innovations we introduce compared to the agent-based macroeconomic framework delineated in the literature is that firms' financial structure is derived from the Dynamic Trade-Off theory. According to this theory, we assume that firms have a "target leverage", that is a desired ratio between debt and net worth, and they try to reach it by following an adaptive rule governing credit demand. This capital structure is already investigated in the agent-based model proposed by Riccetti et al. (2013) that builds upon the previous work by Delli Gatti et al. (2010), which is based on a firms' capital structure given by the Pecking Order theory. The Dynamic Trade-Off theory has a relevant role in influencing the leverage cycle, with important consequences on macroeconomic dynamics.[4]

[4]First of all, our choice of introducing the Dynamic Trade-Off theory in the model is due to empirical reasons, as motivated by the literature on the topic cited above. Moreover, in Delli Gatti et al. (2010) the Pecking Order theory is associated to a different production function and a peculiar sectorial structure of the economy. Besides, that paper is an extension of a previous one (Delli Gatti et al., 2005) which was already based on the Pecking Order theory: Delli Gatti et al. (2010) proposed a way to study the diffusion of

Another important point in the model is the presence of an acyclical sector, here represented by the government that hires public workers so providing a fraction of the aggregate demand. In this way the government partially stabilizes the economy by reducing output volatility. Nevertheless, our model also demonstrates that large and extended crises with large unemployment and a lacking aggregate demand may endogenously emerge. This also means that the model can exhibit unpredictable behaviors and path-dependent trajectories which depend on historical accidents. As in the case of the MOSES model (Eliasson, 1991), the modeler as well as the external observer (and also policy makers) cannot predict the realization of a large crisis, due to the *complexity* of individual and collective behaviors. However, one can detect a tendency of the economic system towards the crisis, as we will see when we discuss model simulations.

The paper is organized as follows. In Section 2 we explain the basic aspects of the modeling framework such as the sequence of events and the matching mechanism. Section 3 presents the working of the four markets which compose our economy. The evolution of agents' wealth is described in Section 4, while the behavior of policy makers is discussed in Section 5. Model dynamics are studied in Section 6 in which we report the simulation results. Moreover, in Section 7 we develop some Monte Carlo experiments in order to: (i) investigate the relationship between financial factors and the real economy, (ii) analyze the peculiar aspects of extended crises. In Section 8 we analyze the role of the government as an employer of public workers: in particular, we study the influence of the public sector's size (and then the interplay between the private economy and the public sector) on macroeconomic dynamics. Section 9 concludes.

2 Model setup

The macroeconomy is populated by individuals ($i = 1, 2, ..., H$), firms ($f = 1, 2, ..., F$), banks ($b = 1, 2, ..., B$), a central bank, and the government, which interact over a time span $t = 1, 2, ..., T$ in the following four markets:

- Credit market: firms and banks.
- Labor market: firms and individuals.
- Goods market: individuals and firms.
- Deposit market: banks and individuals.

bankruptcy in such a framework through adding an upstream sector to Delli Gatti et al. (2005). In presence of a downstream sector characterized by a firm's financial structure based on the Pecking Order theory, the introduction of an upstream sector (without such a financial structure) allowed the model to exhibit bankruptcy avalanches. Instead, in our case we do not need such an assumption, given that the financial structure of firms based on the Dynamic Trade-Off theory allows us to analyze firm and bank defaults in a more natural way.

Agents are boundedly rational and follow (relatively) simple rules of behaviour in an incomplete and asymmetric information context: individuals try to buy consumption goods from the cheapest supplier, they also try to work in the firm offering the highest wage; firms try to accumulate profits by selling their products to individuals (they set the price according to their individual excess demand) and hiring cheapest workers; workers update the asked wage according to their occupational status (upward if employed, downward if unemployed); individuals' saving goes into bank deposits; given the Basel-like regulatory constraints, banks extend credit to finance firms' production; firms choose the banks offering lowest interest rates, while individuals deposit money in the banks offering the highest interest rates. The government hires public workers, taxes private agents and issues public debt. Finally, the central bank provides money to banks and the government given their requirements.

In the following subsections we firstly describe the sequence of events occurring in each period. Subsequently, we explain the working of the matching mechanism which characterizes the interaction structure of all markets.

2.1 Sequence of events

The sequence of events occurring in each period runs as follows:

1. At first firms ask for credit to banks given the demand deriving from their net worth and leverage target. In each period, the leverage level changes according to expected profits and inventories.

2. Banks set their credit supply depending on their net worth, deposits and the quantity of money provided by the central bank. Moreover, they must comply with some regulatory constraints.

3. Banks and firms interact in the credit market. At the end of the matching process, some banks may lend all the available credit supply while others may remain with some residual money; similarly, some firms may obtain the required credit while other may remain credit constrained.

4. The government hires public workers. Moreover, it collects taxes (coming from previous period private incomes and wealth) and, given the wage expenditure for public workers, calculates its deficit (surplus), and updates the overall debt.

5. Banks buy government securities to employ excess liquidity. The central bank purchases the remaining securities.

6. Firms hire workers in the labor market. The labor demand depends on available funds, that is net worth and bank credit. After the labor matching some firms satisfy their

labor demand, while others remain with residual cash; at the same time, some people may remain unemployed. Employed people pay income taxes to the government.

7. Firms produce consumption goods on the basis of hired workers. They put in the goods market their current period production and previous period inventories.

8. Individuals decide their desired consumption on the basis of their wages and wealth (net of taxes).

9. Individuals and firms interact in the goods market. As a result, some individuals satisfy their desired consumption, while others may remain with residual cash; on the other hand, some firms sell all the produced output, while others may accumulate inventories.

10. Individuals determine their savings to be deposited in banks.

11. Firms calculate profits and survival firms repay their debt to banks, pay taxes, and distribute dividends to individuals.

12. Banks calculate profits. Individuals lose (part of) deposited money in case of bank defaults. Survival banks pay taxes and distribute dividends to individuals.

13. Agents update their wealth, on which they pay capital levy.

14. Central bank decides the amount of money to be lent to banks in the following period according to credit demand/supply unbalance.

15. New entrants replace bankrupted agents (firms or banks with negative net worth) according to a one-to-one replacement. New agents enter the system with initial conditions we will define below. Moreover, the money needed to finance entrants is subtracted from individuals' wealth. In the case private wealth is not enough, then government intervenes. Therefore, the model is stock flow consistent given that we do not create new financial resources when new entrants substitute defaulted agents.

2.2 The matching mechanism

In each of the four markets composing our macroeconomy the following matching protocol is at work. In general, two classes of agents interact, that is the demand and the supply sides. One side observes a list of potential counterparts and chooses the most suitable partner according to some market-specific criteria.

At the beginning, a random list of agents in the demand side – firms in the credit market, firms in the labor market, individuals in the goods market, and banks in the deposit market – is set. Then, the first agent in the list observes a random subset of potential partners, whose size depends on a parameter $0 < \chi \leq 1$ (which proxies the degree of imperfect information),

and chooses the cheapest one. For example, in the labor market, the first firm on the list, say the firm f_1 observes the asked wage of a subsample of workers and chooses the agent asking for the lowest one, say the worker i_1.
After that, the second agent on the list performs the same activity on a new random subset of the updated potential partner list. In the case of the labor market, the new list of potential workers to be hired no longer contains the worker i_1. The process iterates till the end of the demand side list (in our example, all the firms enter the matching process and have the possibility to employ one worker).
Then, a new random list of agents in the demand side is set and the whole matching mechanism goes on until either one side of the market (demand or supply) is empty or no further matchings are feasible because the highest *bid* (for example, the money till available to the richest firm) is lower than the lowest *ask* (for example, the lowest wage asked by till unemployed workers).

Given this matching protocol governing agents' interaction, now we describe the details of agents' behavior in the four markets.

3 Markets

3.1 Credit market

Firms and banks interact in this market: firms want to finance production and banks may provide credit to this end. Firm's f credit demand at time t depends on its net worth A_{ft} and the leverage target l_{ft}. Hence, required credit is:

$$B^d_{ft} = A_{ft} \cdot l_{ft} \tag{1}$$

The leverage target is set according to the following rule:

$$l_{ft} = \begin{cases} l_{ft-1} \cdot (1 + \alpha \cdot U(0,1)), & \text{if } \pi_{ft-1}/(A_{ft-1} + B_{ft-1}) > i_{ft-1} \text{ and } \hat{y}_{ft-1} < \psi \cdot y_{ft-1} \\ l_{ft-1}, & \text{if } \pi_{ft-1}/(A_{ft-1} + B_{ft-1}) = i_{ft-1} \text{ and } \hat{y}_{ft-1} < \psi \cdot y_{ft-1} \\ l_{ft-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } \pi_{ft-1}/(A_{ft-1} + B_{ft-1}) < i_{ft-1} \text{ or } \hat{y}_{ft-1} \geq \psi \cdot y_{ft-1} \end{cases} \tag{2}$$

where $\alpha > 0$ is a parameter representing the maximum percentage change of the relevant variable (in this case the target leverage), $U(0,1)$ is a random number picked from a uniform distribution in the interval (0,1), π_{ft-1} is the gross profit (realized in the previous period), B_{ft-1} is the previous period effective debt, i_{ft-1} is the nominal interest rate paid on previous debts,[5] $\hat{y}_{ft-1}$ represents inventories (that is, unsold goods), $0 \leq \psi \leq 1$ is a parameter representing a threshold for inventories based on previous period production y_{ft-1}.

[5]It is a mean interest rate calculated as the weighted average of interests paid to the lending banks.

On the other side, bank b offers a total amount of money B^d_{bt} depending on net worth A_{bt}, deposits D_{bt}, central bank credit m_{bt}, and some legal constraints (proxied by the parameters $\gamma_1 > 0$ and $0 \leq \gamma_2 \leq 1$ that represents respectively the maximum admissible leverage and maximum percentage of capital to be invested in lending activities):

$$B^d_{bt} = min(\hat{k}_{bt}, \bar{k}_{bt}) \tag{3}$$

where $\hat{k} = \gamma_1 \cdot A_{bt}$, $\bar{k} = \gamma_2 \cdot A_{bt} + D_{bt-1} + m_{bt}$. Moreover, in order to reduce risk concentration, banks lend to a single firm up to a maximum fraction β of the total amount of the credit B^d_{bt}. This behavioural parameter can be also interpreted as a regulatory constraint to avoid excessive concentration.

The interest rate charged by the bank b on the firm f at time t is given by:

$$i_{bft} = i^{CB}_t + \hat{i}_{bt} + \bar{i}_{ft} \tag{4}$$

where i^{CB}_t is the nominal interest rate set by the central bank at time t, $\hat{i}_{bt}$ is a bank-specific component, and $\bar{i}_{ft} = \rho^{\,l_{ft}}/100$ is a firm-specific component, that is a risk premium on firm target leverage.

The bank-specific component evolves as follows:

$$\hat{i}_{bt} = \begin{cases} \hat{i}_{bt} \cdot (1 - \alpha \cdot U(0,1))\,, & \text{if } \hat{B}_{bt-1} > 0 \\ \hat{i}_{bt} \cdot (1 + \alpha \cdot U(0,1))\,, & \text{if } \hat{B}_{bt-1} = 0 \end{cases} \tag{5}$$

where $\hat{B}_{bt-1}$ is the amount of money that the bank did not manage to lend to firms in the previous period.

Given this setting on credit supply and demand, firms and banks interact according to the matching mechanism. As a consequence, each firm ends up with a credit $B_{ft} \leq B^d_{ft}$ and each bank lends to firms an amount $B_{bt} \leq B^d_{bt}$. The difference between desired and effective credit is equal to $B^d_{ft} - B_{ft} = \hat{B}_{ft}$ and $B^d_{bt} - B_{bt} = \hat{B}_{bt}$, for firms and banks respectively. Moreover, we hypothesize that banks ask for an investment in government securities equal to $\Gamma^d_{bt} = \bar{k}_{bt} - B_{bt}$.[6] If the sum of desired government bonds exceeds the amount of outstanding public debt then the effective investment Γ_{bt} is rescaled according to a factor $\Gamma^d_{bt}/\sum \Gamma^d_{bt}$. Instead, if public debt exceeds the banks' desired amount, then the central bank buys the difference.

[6] We consider government bonds as risk free assets. Banks that do not manage to lend all the disposable money, decide to invest in government bonds to obtain a small but positive risk free return able to cover the return paid on deposits. In the case $\bar{k}$ is smaller than $\hat{k}$ the bank has not enough money to lend, and then it cannot reach the maximum admissible leverage on risky assets. On the contrary, when $\hat{k}$ is smaller than $\bar{k}$ the bank has an excess of money with respect to the amount that it can invest in risky assets. As a consequence, the bank buy government securities obtaining the remuneration given by the risk free rate.

3.2 Labor market

In each period, workers post a wage w_{it} which is updated according to the following rule:

$$w_{it} = \begin{cases} w_{it-1} \cdot (1 + \alpha \cdot U(0,1)), & \text{if } i \text{ employed at time } t-1 \\ w_{it-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } i \text{ unemployed at time } t-1 \end{cases} \tag{6}$$

However, the required wage has a minimum related to the price of a single good net of income tax.

The government hires a randomly selected fraction g of individuals. The remaining part is available for working in the firms. Firm's f labor demand depends on the total capital available: $A_{ft} + B_{ft}$. Hence, given this amount, a firm hires a worker. Then, the firm hires another worker, if the residual money is enough and so on. Given this setting on labor supply and demand, firms and individuals interact according to the matching mechanism. As a consequence, each firm ends up with a number of workers n_{ft} and residual cash (insufficient to hire an additional worker). Obviously, a fraction of individuals may remain unemployed. For the sake of simplicity, the wage of unemployed people is set equal to zero.

3.3 Goods market

In this market individuals represent the demand side, while firms are the supply side. Individuals set the desired consumption as follows:

$$c^d_{it} = c_1 \cdot w_{it} + c_2 \cdot A_{it} \tag{7}$$

where $0 < c_1 \leq 1$ is the propensity to consume current income, $0 \leq c_2 \leq 1$ is the propensity to consume the wealth A_{it}. If the amount c^d_{it} is smaller than the average price of one good $\bar{p}$ then $c^d_{it} = min(\bar{p}\ , w_{it} + A_{it})$. By summing up the consumption of individuals we obtain the aggregate demand. It is worth noticing that current income derives from both a cyclical private industrial sector and an acyclical public service sector.

Firm f produces an amount of goods given by:

$$y_{ft} = \phi \cdot n_{ft} \tag{8}$$

where $\phi \geq 1$ is a productivity parameter.

The firm tries to sell this produced amount plus the inventories $\hat{y}_{ft-1}$. The selling price evolves according to this rule:

$$p_{ft} = \begin{cases} p_{ft-1} \cdot (1 + \alpha \cdot U(0,1)), & \text{if } \hat{y}_{ft-1} = 0 \text{ and } y_{ft-1} > 0 \\ p_{ft-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } \hat{y}_{ft-1} > 0 \text{ or } y_{ft-1} = 0 \end{cases} \tag{9}$$

However, the minimum price is set such that it is at least equal to the average cost of production.

Given this setting on goods supply and demand, individuals and firms interact according to the matching mechanism. As a consequence, each individual ends up with a residual cash, that is not enough to buy an additional good and that she will try to deposit in a bank. On the other hand, firms sell an amount $0 \leq \bar{y}_{ft} \leq y_{ft}$ and they may remain with unsold goods (that is, the inventories $\hat{y}_{ft} = y_{ft} - \bar{y}_{ft}$ that the firm will try to sell in the next period).

3.4 Deposit market

In the deposit market, banks represent the demand side (because they require capital to extend credit) and individuals are on the supply side. Banks offer an interest rate on deposits according to their funds requirement:

$$i^D_{bt} = \begin{cases} i^D_{bt-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } \bar{k}_{bt} - B_{bt} - \Gamma_{bt} > 0 \\ min\{i^D_{bt-1} \cdot (1 + \alpha \cdot U(0,1)), i_{CBt}\}, & \text{if } \bar{k}_{bt} - B_{bt} - \Gamma_{bt} = 0 \end{cases} \tag{10}$$

where Γ_{bt} is the amount of public debt bought by bank b at time t. Hence, the previous equation states that if a bank exhausts the credit supply by lending to private firms or government then it decides to increase the interest rate paid on deposits, so to attract new depositors, and vice versa. However, the interest rate on deposits can increase till a maximum given by the policy rate i^{CB}_t which is both the rate at which banks could refinance from the central bank and the rate paid by the government on public bonds.

individuals set the minimum interest rate they want to obtain on bank deposits as follows:

$$i^D_{it} = \begin{cases} i^D_{it-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } D_{it-1} = 0 \\ i^D_{it-1} \cdot (1 + \alpha \cdot U(0,1)), & \text{if } D_{it-1} > 0 \end{cases} \tag{11}$$

where D_{it-1} is the individual i's deposit in the previous period. This means that an individual that found a bank paying an interest rate higher or equal to the desired one decides to ask for a higher remuneration. In the opposite case, she did not find a bank satisfying her requirements, thus she kept her money in cash and now she asks for a lower rate. We assume that an individual deposits all the available money in a single bank that offers an adequate interest rate. In the opposite case, she does not accept to deposit her cash for an interest rate below the desired one.

4 Wealth evolution

4.1 Firms

According to the outcomes of the credit, labor and goods markets, the firm f's profit is equal to:

$$\pi_{ft} = p_{ft} \cdot \bar{y}_{ft} - W_{ft} - I_{ft} \tag{12}$$

where W_{ft} is the firm f's wage bill, that is the sum of wages paid to employed workers, and I_{ft} is the sum of interests paid on bank loans.

Firms pay a proportional tax τ on positive profits; negative profits are subtracted in the computation of the taxes that should be paid on the next positive profits. We indicate net profits with $\bar{\pi}_{ft}$.

Finally, firms pay a percentage δ_{ft} as dividends on positive net profits. The fraction $0 \leq \delta_{ft} \leq 1$ evolves according to the following rule:

$$\delta_{ft} = \begin{cases} \delta_{ft-1} \cdot (1 - \alpha \cdot U(0,1)), & \text{if } \hat{y}_{ft} = 0 \text{ and } y_{ft} > 0 \\ \delta_{ft-1} \cdot (1 + \alpha \cdot U(0,1)), & \text{if } \hat{y}_{ft} > 0 \text{ or } y_{ft} = 0 \end{cases} \tag{13}$$

Therefore, if the firm sold all its output in the previous period, then it decides to retain a larger fraction of profits to enlarge the production. Instead, if the firm faced an excess supply and then it has inventories to sell, it decides to distribute more profits as dividends, given that it does not need to produce more and more. We indicate the profit net of taxes and dividends as $\hat{\pi}_{ft}$. Obviously, in case of negative profits $\hat{\pi}_{ft} = \pi_{ft}$.

Thus, the firm f's net worth evolves as follows:

$$A_{ft} = (1 - \tau') \cdot [A_{ft-1} + \hat{\pi}_{ft}] \tag{14}$$

where τ' is the tax rate on wealth (applied only on wealth exceeding a threshold $\bar{\tau'} \cdot \bar{p}$, that is a multiple of the average goods price).

If $A_{ft} \leq 0$ then the firm goes bankrupt and a new entrant takes its place. The initial net worth of the new entrant is a multiple of the average goods price, while the *target* leverage is one. Moreover, the initial price is equal to the mean price of survival firms. Banks linked to defaulted firms lose a fraction of their loans (the loss given default rate is calculated as $(A_{ft} + B_{ft})/B_{ft}$).

4.2 Banks

As a consequence of operations in the credit and the deposit markets, the bank b's profit is equal to:

$$\pi_{bt} = int_{bt} + i_t^{\Gamma} \cdot \Gamma_{bt} - i_{bt-1}^{D} \cdot D_{bt-1} - i_t^{CB} \cdot m_{bt} - bad_{bt} \tag{15}$$

where int_{bt} represents the interests gained on lending to non-defaulted firms, i_t^{Γ} is the interest rate on government securities (Γ_{bt}), and bad_{bt} is the amount of "bad debt" due to bankrupted firms, that is non performing loans. Bad debt is the loss given default of the total loan, that is a fraction $1-(A_{ft}+B_{ft})/B_{ft}$ of the loan to defaulted firm f connected with bank b.

Banks pay a proportional tax τ on positive profits; negative profits will be used to reduce taxes paid on the next positive profits. We indicate net profits with $\bar{\pi}_{bt}$.
Finally, banks pay a percentage δ_{bt} as dividends on positive net profits. The fraction $0 \leq \delta_{bt} \leq 1$ evolves according to the following rule:

$$\delta_{bt} = \begin{cases} \delta_{bt-1} \cdot (1 - \alpha \cdot U(0,1))\,, & \text{if } \; B_{bt} > 0 \text{ and } \hat{B}_{bt} = 0 \\ \delta_{ft-1} \cdot (1 + \alpha \cdot U(0,1))\,, & \text{if } \; B_{bt} = 0 \text{ or } \hat{B}_{bt} > 0 \end{cases} \tag{16}$$

Indeed, if the bank does not manage to lend the desired supply of credit then it decides to distribute more dividends (because it does not need high reinvested profits), and vice versa.

We indicate the profit net of taxes and dividends as $\hat{\pi}_{bt}$. Obviously, in case of negative profits $\hat{\pi}_{bt} = \pi_{bt}$.
Thus, the bank b's net worth evolves as follows:

$$A_{bt} = (1-\tau') \cdot [A_{bt-1} + \hat{\pi}_{bt}] \tag{17}$$

where τ' is the tax rate on wealth (applied only on wealth exceeding a threshold $\bar{\tau'} \cdot \bar{p}$, that is a multiple of the average goods price).

If $A_{bt} \leq 0$ then the bank is in default and a new entrant takes its place. Individuals linked to defaulted banks lose a fraction of their deposits (the loss given default rate is calculated as $(A_{bt}+D_{bt})/D_{bt}$). The initial net worth of the new entrant is a multiple of the average goods price. Moreover, the initial bank-specific component of the interest rate ($\hat{i}_{bt}$) is equal to the mean value across banks.

4.3 Individuals

According to the outcomes of the labor, goods, and deposit markets, the individual i's wealth evolves as follows:

$$A_{it} = (1-\tau') \cdot [(A_{it-1} + (1-\tau) \cdot w_{it} + div_{it} + int^D_{it} - c_{it}] \tag{18}$$

where τ' is the tax rate on wealth (applied only on wealth exceeding a threshold $\bar{\tau'} \cdot \bar{p}$, that is a multiple of the average goods price), τ is the tax rate on income, w_{it} is the wage gained by employed workers, div_{it} is the fraction (proportional to the individual i's wealth compared to overall individuals' wealth) of dividends distributed by firms and banks net of the amount of resources needed to finance new entrants (hence, this value may be negative), int^D_{it} represents interests on deposits, and $c_{it} \leq c^d_{it}$ is the effective consumption. Individuals linked to defaulted banks lose a fraction of their deposits as already explained above.

5 Government and central bank

On the one hand, the government's current expenditure is given by the sum of wages paid to public workers (G_t), the interests paid on public debt to banks, and an amount Ω_t which is normally zero but for extreme cases in which the government has to intervene to finance new entrants when private wealth is not enough. On the other hand, government collects taxes on incomes and wealth, and receives interests gained by the central bank. The difference between expenditures and revenues is the public deficit Ψ_t. Consequently, public debt is $\Gamma_t = \Gamma_{t-1} + \Psi_t$.

Central bank decides the policy rate i_t^{CB} and put a quantity of money into the system in accordance with it. In order to do that, the central bank observes the aggregate excess supply or demand in the credit market and sets an amount of money M_t to reduce the gap in the following period.

6 Simulations

We run a baseline simulation for a time span of T =150 periods and analyze the results for the last 50 (so the first 100 are used to initialize the model). Table 1 shows the parameter setting of the baseline simulation. The initial agents' wealth is set as follows: $A_{f1} = max\{0.1, N(3,1)\}$, $A_{b1} = max\{0.2, N(5,1)\}$, $A_{h1} = max\{0.01, N(0.5, 0.01)\}$. The policy rate i_t^{CB} is constant at 1%.

Simulation results are displayed in Figure 1 and show that endogenous business cycles emerge as a consequence of the interaction between real and financial factors. When firms' profits are improving, they try to expand the production and, if banks extend the required credit, this results in more employment; the decrease of the unemployment rate leads to the rise of wages that, on the one hand, increases the aggregate demand, while on the other hand reduces firms' profits, and this may cause the inversion of the business cycle. This feature of the business cycle is described in Figure 2 where we show the cross-correlation between the unemployment rate and the firms' profit rate.[7] First of all, there is a high positive correlation at lag 0: the profit rate is high when unemployment is high given that firms save on production costs (e.g., wage bill) but, at the same time, the aggregate demand does not decrease proportionally, because of public workers' expenditure and consumption due to wealth, thus firms can sell their commodities (including inventories) in the goods market. However, the presence of unemployed people, the tendency of wages to decrease due to the high unemployment rate, and the reduction of individuals' wealth, cause the fall of next period aggregate demand that, in turn, reduces firms' profits. Indeed, Figure 2 displays a negative correlation at lag +1. Instead, the negative correlation at lag -1 means that increasing profits boost the

[7] In order to obtain a more statistical significant result we extended the simulation period to T=500.

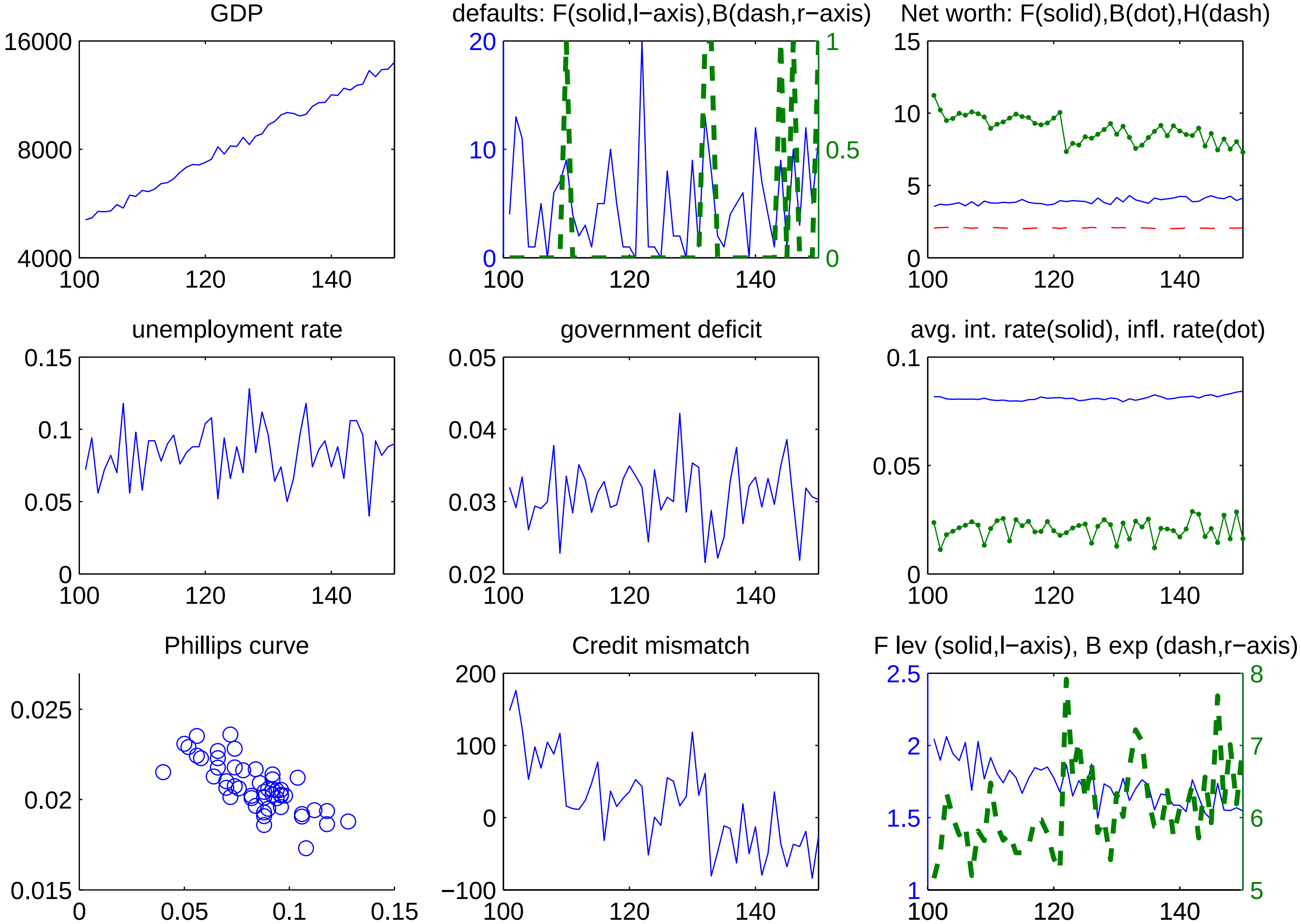


Figure 1: Baseline model: Simulation results

Table 1: Parameter setting

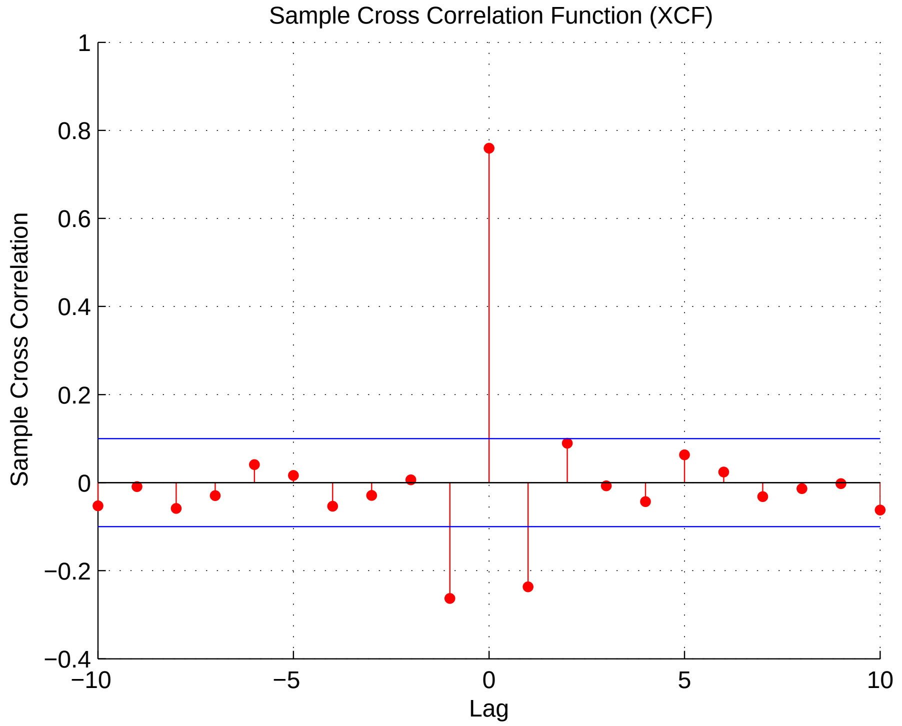
H	number of individuals	500
F	number of firms	80
B	number of banks	10
α	adjustment parameter	0.05
χ	matching imperfect information	0.2
ψ	inventory threshold	0.1
γ_1	max bank's leverage	10
γ_2	max % of bank's invested capital in lending	0.5
β	max bank's lending to single firm	0.5
ρ	risk premium on firm's loan	2
c_1	propensity to consume current income	0.8
c_2	propensity to consume wealth	0.3
ϕ	firm's productivity	3
τ	tax rate on income	0.3
τ'	tax rate on wealth	0.05
$\bar{\tau}'$	threshold for tax on wealth	3
g	% of public workers on population	0.33

expansion of the economy and then a fall of the unemployment rate follows.[8]

The two major innovations we introduce in this agent-based framework, that is (i) the Dynamic Trade-Off theory for firms' capital structure and its interplay with banks' credit supply, (ii) the role of an acyclical sector, have opposite effects on business fluctuations. On one hand, firms' leverage and, in particular, banks' exposure enlarge business fluctuations: a growing firm requires more credit and, if banks extended new loans, then they are able to expand the production through the employment of more workers; after a while, the rise of employment fosters wages that, together with the rise of interest payments on an increasing debt, reduces firms' profitability. Thus the business cycle reverses and financial factors amplify the fall of production (the relatively low level of profits with respect to interest payments induces a

[8] This short business cycle of around three periods could be enlarged by changing the parameter setting. For instance, assuming a different adjustment parameter of prices and wages can impact the macroeconomic system. We tried a simulation with parameter α used in equation 9 equal to 0.10, that is, prices move more rapidly than wages, in a more realistic setting. The macroeconomic system acts similarly to the baseline setting, but the business cycle is longer and more volatile, and the mean unemployment rate is higher, with a higher probability of large crises. More in general, the mismatch between the two mechanism enlarges the unemployment (and then the output) volatility. However, the analysis of different adjustment speeds deserves a deeper study, and it should be very important to simulate asymmetric behaviours (for instance wages and prices could be represented with a stronger rigidity in reductions than in rises). Moreover, an accurate parameter calibration is needed, but should be founded on a more complete model, that we aim to develop starting from this framework.

Figure 2: Unemployment rate and firms' profit rate.



deleveraging process). In other words, credit is pro-cyclical. In particular, there is a negative but modest correlation between firms' leverage and the unemployment rate (-0.1539), while there is a more significant negative correlation between banks' exposure and unemployment (-0.3670). This simulation result is consistent with the empirical evidence on the topic (see, for instance, Kalemli-Ozcan et al., 2011). Accordingly, banks' capitalization plays a relevant role in determining credit conditions, so influencing firms' leverage and, in general, the macroeconomic evolution. On the other hand, the presence of an acyclical sector, here represented by the government, has a fundamental role in sustaining the aggregate demand and in mitigating output volatility.

The nominal GDP grows along time as a consequence of price inflation (given that there is no productivity growth in the baseline model). The average inflation rate is 2.07% with a minimum of 1.12% and a maximum of 2.87%. The unemployment rate oscillates around 8.42% with a minimum of 4% and a maximum of 12.8%. Model simulation reproduces a Phillips curve, which is a negative relationship between wage inflation and unemployment rate (the correlation coefficient is -0.76). The average fraction of firms going bankrupt is 6.3%, with a minimum of zero and a maximum of 25%. The average fraction of bank defaults is 1.2%, with a minimum of zero and a maximum of 10%. Bank's leverage is inversely related to bank's net worth. The per-capita average banks' net worth (in real terms) is 8.91 (min 7.30, max 11.23). Moreover, credit mismatch (that is the difference between banks' credit supply and firms' credit demand) tends to follow the cycle of banks' net worth: when banks are poorly capitalized this results in credit rationing for firms; in this case, the central bank intervenes providing credit to banks; on the contrary, when banks are well capitalized they are able to fulfill all credit demand. Accordingly, firms' mean leverage is influenced by credit availability. The mean interest rate charged by banks on firm loans is 8.11%. Per-capita individuals wealth (in real terms) is stable around 2.06 (min 2.01, max 2.10), while the same value for firms is equal to 3.91 (min 3.54, max 4.31). Finally, the average ratio between public deficit and GDP is equal to 3.09% (min 2.16%, max 4.22%). It is worth to note that the presence of the government, nevertheless the relatively low level of public deficit, allows for the nominal growth in the model. This outcome also depends on the working of the central bank that finances the government buying public securities charging a low interest rate.

7 Monte Carlo analysis

In order to check the robustness of our findings, we performed 1000 Monte Carlo simulations of the baseline model. The first result of this computational experiment is that in some replications the economy completely crashes and the unemployment rate reaches very large values. To identify the worst case scenarios we set a threshold for the average unemployment rate equal to 20%. Then, we discard the five simulations with an average unemployment rate (computed over the time span 101-150) above the threshold. The statistics of the Monte Carlo experiment on the remaining 995 simulations are reported in Table 2. The results describe the average macroeconomic behaviour of the system, showing that mean variables values are quite stable across repeated simulations. The only two variables which are more unstable across simulations are: the credit constraint (that is, the fraction of firms' required credit not fulfilled by banks), and the bank exposure (calculated as the amount of credit lent to firms divided by net worth). The latter variable has a relevant procyclical impact on the economy, that is there is a significant negative correlation between bank exposure and unemployment. In particular, the mean value across simulations is equal to -50.09% (with a standard deviation of 16.03%).

7.1 Financial factors and the real economy

Now we analyze in more detail the relationship between financial variables, like firm leverage and bank exposure, and the unemployment rate (which represents the main real variable in our macroeconomic framework). First of all, the correlation between firm leverage and the unemployment rate is around -0.2, while the correlation between bank exposure and the unemployment rate is around -0.3. Then, the expansionary phase of the business cycle is boosted by financial factors through a leveraging process, while the recession is amplified by the deleveraging.

Figure 3 shows that there is a negative non-linear relation between firm leverage and unem-

Figure 3: Firm leverage and unemployment rate.

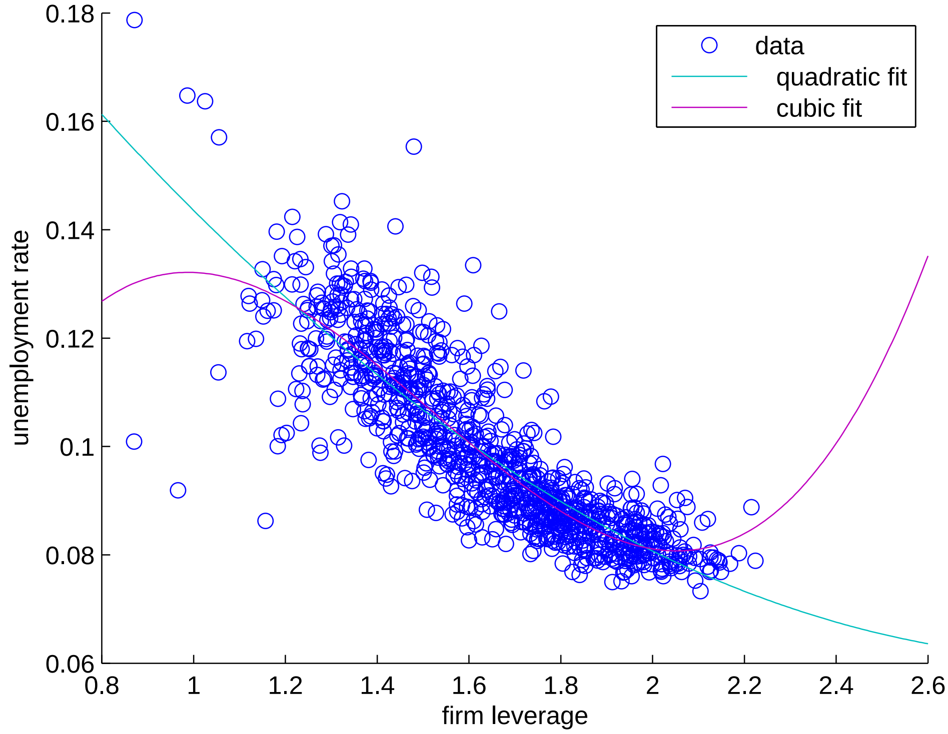


Figure 4: Bank exposure and unemployment rate.

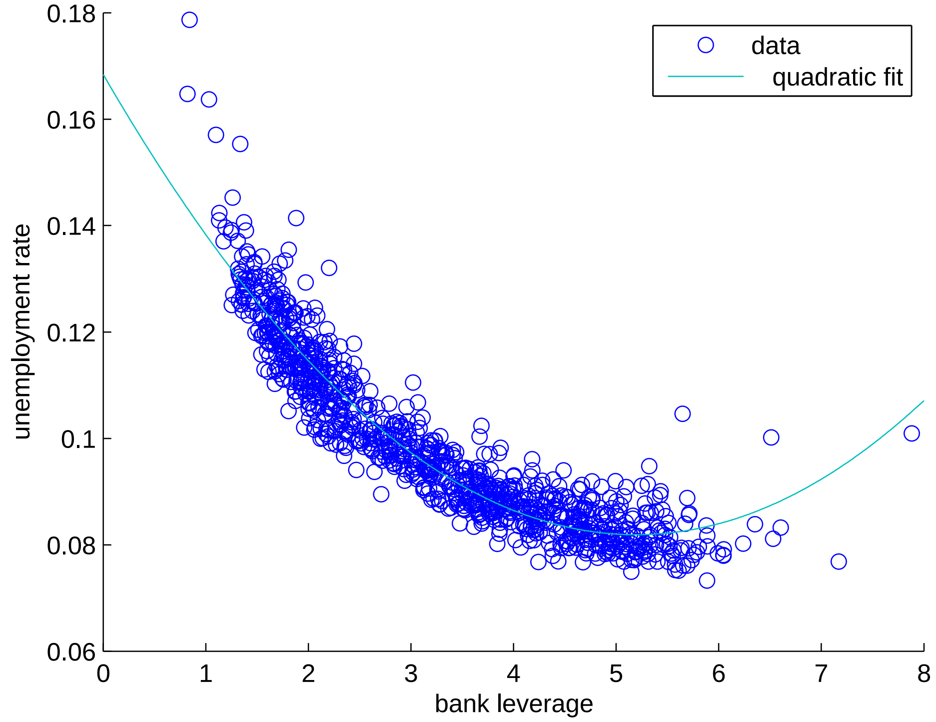


Table 2: Monte Carlo replications: mean values and corresponding standard deviation (calculated over the time span 101-150) of 995 simulations with average unemployment rate below 20%.

Variable	Mean	St. Dev.
Unemployment rate	9.92%	1.63%
Unemployment volatility	2.05%	0.48%
Firm default rate	6.45%	2.10%
Bank default rate	0.57%	0.57%
Wage share	63.4%	0.53%
Public deficit	3.26%	0.19%
Interest rate	9.11%	1.93%
Inflation rate	1.99%	0.07%
Credit constraint	14.83%	8.23%
Firm mean leverage	1.65	0.24
Bank mean exposure	3.27	1.30
Firm leverage volatility	0.12	0.04
Bank exposure volatility	0.51	0.33

ployment. It is worth to note that for relatively high levels of firm leverage the unemployment rate tends to be smaller and less volatile. However, for largest values of the firm leverage (above 2) the negative relation with the unemployment rate tends to disappear or rather it reverses (as shown by the cubic fit in the Figure).[9]

Figure 4 shows that a non-linear relation between bank exposure and unemployment emerges. In particular, for low levels, an increase of bank exposure reduces the rate of unemployment. Instead, for high levels of bank exposure (that is, above 5) a further increase makes the unemployment higher. In other words, if banks increase their exposure enlarging credit to firms, the latter hire more workers and the unemployment rate decreases. But, when the exposure of banks becomes "excessive" this leads to instability (more failures) and an increase of the

[9] We test if the quadratic and cubic coefficients fit the data with a t-test on the two coefficients and a F-test on both coefficients jointly: all the tests strongly reject (at 99% confidence level) the null hypothesis that the coefficients are equal to zero. Moreover, all the information criteria (Akaike, Schwartz and Hannan-Quinn) select the cubic fit as the best. The information criteria also signal that the cubic fit overperforms the fourth degree polynomial fit and the coefficient of the fourth degree component is not statistically significant. The equation of the cubic fit, where U is the unemployment rate and L_f is the aggregate firm leverage level, is the following:

$$U = -0.08 + 0.52 * L_f - 0.39 * L_f^2 + 0.08 * L_f^3$$

unemployment rate follows[10].

7.2 Large crises

In the previous Monte Carlo experiment we observe 5 out of 1000 cases characterized by a large mean unemployment rate (during the period from $t = 101$ to $t = 150$). This means that large crises can appear in the macroeconomic system. Moreover, in some simulations we note that the time series of the main macroeconomic variables are non-stationary. In order to check the presence of endogenous regime switches, e.g. from a "normal" period (with average values of variables close to those in Table 2) to a large and extended crisis, we perform an additional Monte Carlo experiment with 100 simulations over a time span of 500 periods (for the same reasons explained above, we discard the first 100 periods of each simulation). However, this is not a long run growth analysis given that some relevant elements for such an analysis, like physical capital, are missing from the current version of the model. Moreover, these elements could also influence the likelihood of large crisis. For instance, the MOSES model proposed by Eliasson (1991) incorporates many characteristics related to long-run growth factors such as innovation dynamics (which in turn influence the important process of entry and exit). In such a complex economic system, unpredictable behaviors and path-dependent trajectories can emerge and the external observer as well as the policy maker cannot predict the realization of crisis episodes. Given that unpredictable large crises can also emerge in our simplified framework (that is, even if long-run growth factors are absent from the model), we think that an extended version of our modeling framework in which innovation dynamics are considered and the entry-exit process is endogenously determined (on the basis of expected profitability) can give rise to even more interesting results regarding the interplay between business fluctuations and endogenous growth.

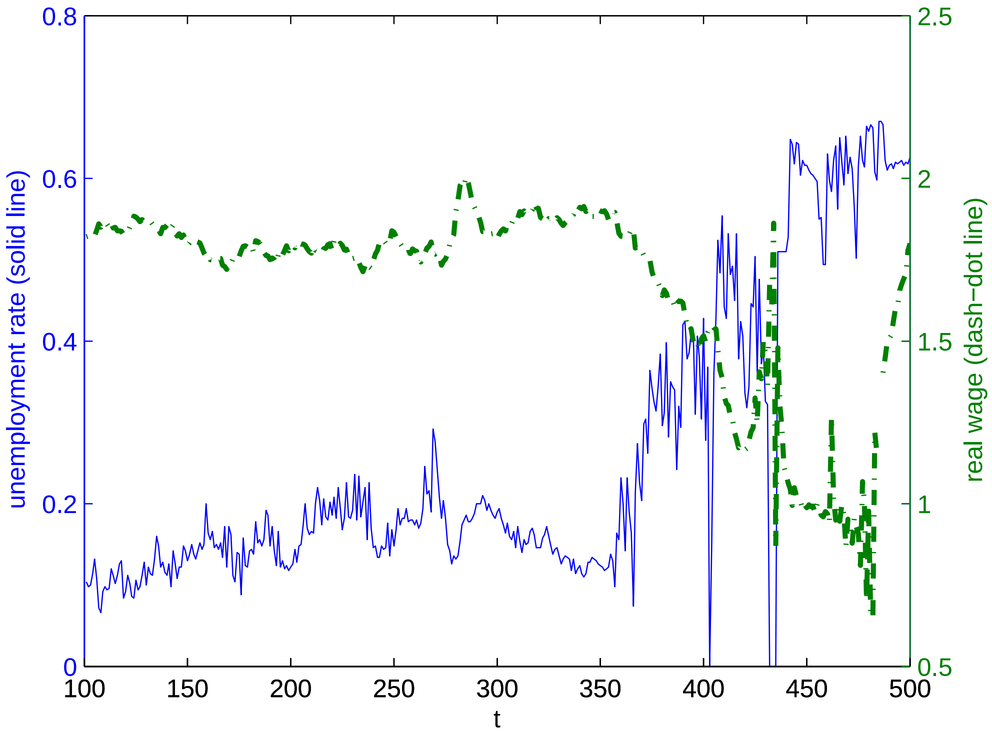
As for simulation results, in 2 out of 100 simulations the macroeconomic system evolves towards an "extended crisis" scenario, where the private sector tends to disappear, with an unemployment rate above 60%, thus almost only public workers remain employed. In this case, as shown in Figure 5, differently from the usual business cycle mechanism, the decrease of wages due to growing unemployment does not reverse the cycle, but rather amplifies the recession due to the lack of aggregate demand. In other words, the self-adjustment mechanism which spontaneously reverses the business cycle (e.g., the rise of the unemployment rate reduces the real wage and then the resulting increase of profits makes room for an expansionary production phase) does not work. Indeed, real wage lowers excessively boosting a vicious circle for which the fall of purchasing power prevents firms to sell commodities, then firms reduce

[10] The equation of the quadratic fit, where U is the unemployment rate and L_b is the aggregate bank exposure level, is the following:

$$U = 0.168 - 0.033 * L_b + 0.003 * L_b^2$$

Both coefficients are statistically significant at 99% level.

Figure 5: The extended crisis case: unemployment rate and real wage.



production, unemployment continues to rise, and the system moves towards a devastating crisis.

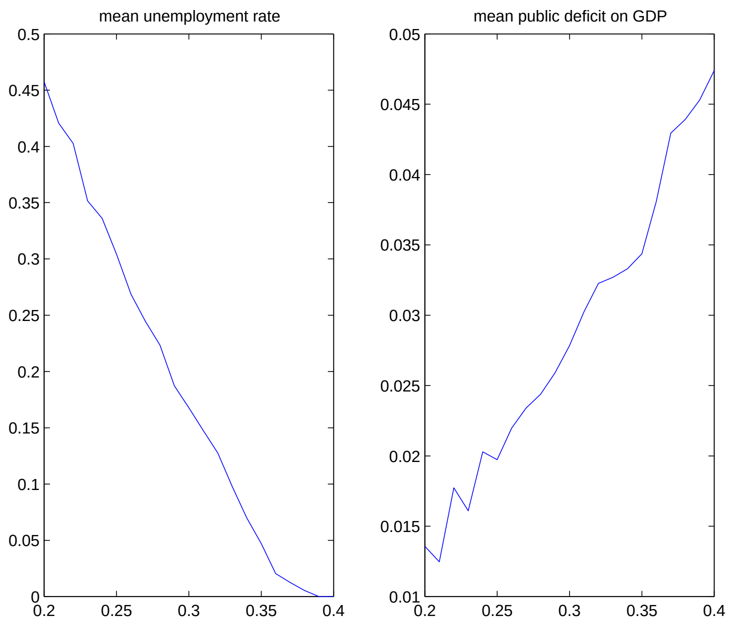
In particular, in one of the two extended crises detected in the Monte Carlo experiment, the production system completely crashes and cannot escape this trap without an exogenous intervention. Instead, in the case explained above, the production system does not completely disrupt, then we cannot exclude a recovery in the very long run. But, accordingly to Keynes, "in the long run we are all dead".

8 A sensitivity analysis wrt. parameter g

Government needs workers to manage the public balance sheet, for instance collecting income and wealth taxes on individuals, firms and banks, issuing government bonds, paying interest on debt, managing the relation with the central bank. Providing services to the economy, the public sector represents the "third sector", that is an important part of the aggregate demand, which is less unstable compared to the "industrial sector". We show the importance of the acyclical sector with two sensitivity analyses on the parameter g (the percentage of public workers on total population).

In the first analysis, we run 20 simulations (time span T=150) for each of the 21 values of the parameter g ranging from 20% to 40%, with step 1%, for a total of 420 simulations. The

Figure 6: Average unemployment rate and average public deficit on GDP: sensitivity analysis wrt. the parameter g ranging from $g = 20\%$ to $g = 40\%$ with step 1% (20 simulations for each step).



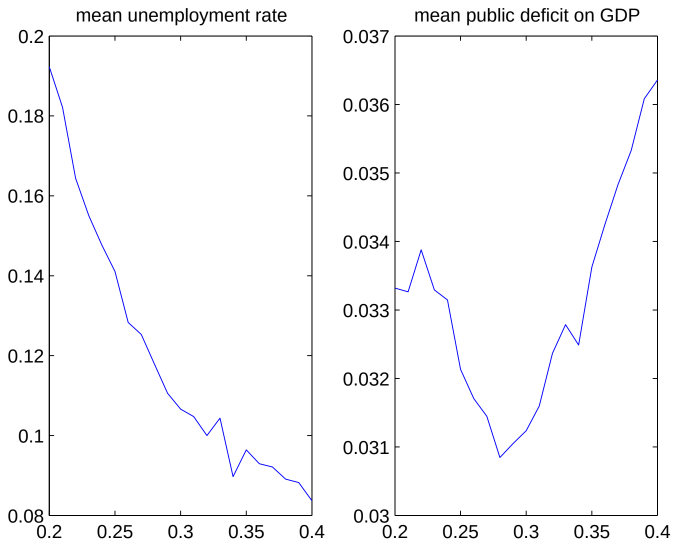
mean unemployment rate and the mean public deficit on GDP in the last 50 periods of the simulation ($101 \leq t \leq 150$) are reported in Figure 6. It clearly emerges that a larger acyclical sector implies a lower average unemployment rate: when $g = 20\%$ the mean unemployment rate is at 46.8%, while the system reaches full employment when $g = 39\%$. Also the standard deviation of the unemployment rate largely changes among simulations, ranging from 8.3% when $g = 20\%$ to 0 if $g = 39\% - 40\%$. Thus, we can observe that an increase of 1% in public employment, corresponds to about a 2.5% overall employment growth, that is if the government hires two additional workers, this also supplies money to the economy such that the private sector is able to hire three additional workers, with a multiplicative effect via the aggregate demand growth.

However, in this analysis we face a large increase of the public deficit from the case of $g = 20\%$ to the case of $g = 39\%$ (the case of $g = 40\%$ is useless, given that there is no reason for the government to hire a fraction of individuals above 39%, because the system is already in a full employment situation): it passes from below 2% to over 4.5% yearly. Thus, the economic growth could be due to the increasing public deficit (with an inflationary consequence: the inflation ranges from -0.2% when $g = 20\%$ to about 2.5% when $g = 40\%$).[11]

In order to stabilize the public deficit at a common level among the simulations (about 3%),

[11] The public deficit decrease from $g = 20\%$ to $g = 23\%$, given that the public expenditure is more than compensated by the economic growth and the related tax revenues.

Figure 7: Average unemployment rate and average public deficit on GDP: sensitivity analysis on parameters g and τ ranging from $g = 20\%$ to $g = 40\%$ and from $\tau = 17\%$ to $\tau = 37\%$, both with step 1% (20 simulations for each step).



we repeat the sensitivity analysis changing at the same time both the value of g ranging from 20% to 40%, and the tax rate on income τ, starting from $\tau = 17\%$ to $\tau = 37\%$, with step 1% (in this way a value of $g = 33\%$ corresponds to a $\tau = 30\%$, as in the baseline setting). Also in this case we run 20 simulations for each step, for a total of 420 simulations. The mean unemployment rate and the mean public deficit on GDP in the last 50 periods of the simulation are reported in Figure 7. We can confirm the previous findings also in this case, that is a larger acyclical sector implies a lower average unemployment rate: when $g = 20\%$ (and $\tau = 17\%$) the mean unemployment rate is above 20% (20.14%), while when $g = 40\%$ (and $\tau = 37\%$) it is below 8% (7.71%). The deficit on GDP is quite stable (3.29% when $g = 20\%$ and 3.51% when $g = 40\%$). However, in this case, the difference between the two extreme cases is much smaller ($46.8\% - 0\%$ in the previous sensitivity analysis, versus $20.14\% - 7.71\%$ in the current one), given that when $g = 20\%$ there is also a much lower tax rate and the private "industrial" sector manages to expand its labor force to about 60% of the individuals from about 50% when g approaches 40%. Moreover, the standard deviation of the unemployment rate does not largely change among simulations, always remaining about $2 - 3\%$, and the inflation rate always remains between 1.4% and 2.1%.

9 Concluding remarks and future research

We present an agent-based macroeconomic model in which heterogeneous agents (individuals, firms and banks) interact according to a fully decentralized matching mechanism. The matching protocol is common to all markets (goods, labor, credit, deposits) and represents a best partner choice in a context of imperfect information.

Model simulation shows that decentralized interactions among heterogeneous entities give rise to emergent macroeconomic properties like the growth of nominal GDP, the fluctuation of the unemployment rate, the presence of the Phillips curve, the relevance of leverage cycles and credit constraints on economic performance, the presence of bank defaults and the role of financial instability, and the importance of government in providing a fraction of the aggregate demand and then as an acyclical sector which stabilize the economy. In particular, simulations show that endogenous business cycles emerge as a consequence of the interaction between real and financial factors: when firms' profits are improving, they try to expand the production and, if banks extend the required credit, this results in more employment; the decrease of the unemployment rate leads to the rise of wages that, on the one hand, increases the aggregate demand, while on the other hand reduces firms' profits, and this may cause the inversion of the business cycle, and then the recession is amplified by the deleveraging process.

Monte Carlo simulations show that model findings are quite robust. A particularly relevant result is that a non-linear relation between firms leverage and unemployment emerges: for relatively high levels of firms leverage the unemployment rate tends to be smaller and less volatile. However, for largest values of the firms leverage the negative relation with the unemployment rate tends to reverse. Also banks' exposure and unemployment are non-linearly related: for low levels, an increase of banks' exposure reduces the rate of unemployment; instead, for high levels of banks' exposure a further increase makes the unemployment higher. In other words, if banks increase their exposure enlarging credit to firms, the latter hire more workers and the unemployment rate decreases. But, when the exposure of banks becomes "excessive" this leads to instability (more failures) and an increase of the unemployment rate follows. All in all, firms leverage and banks exposure may support the working of the economy (reducing the unemployment rate), but when the levels of both leverage and exposure turn to be excessive, the economy becomes too financially fragile (and unemployment may rise).

Moreover, model simulations highlight that even extended crises can endogenously emerge with a strong reduction of real wages, a consequent fall of the aggregate demand that, in turn, induces firms to decrease production, so enlarging the unemployment rate, in a vicious positive feedback circle. In these cases, the system may remain trapped without the possibility to spontaneously recover unless an exogenous intervention takes place.

Our modeling framework can be useful to understand the effects of some policy or institutional changes. Indeed, in future developments we will analyze the sensitivity of simulation results to different parameter settings. Moreover, we will also investigate the consequences of alternative assumptions such as the effect of fiscal and monetary policies, labor market rigidity (in particular downward wage rigidity), heterogeneous consumption behavior, etc. Other central features we want to introduce are an endogenous entry process (related to expected profit), and a different timing for individual decision making (dissynchronization). Finally, the baseline model presented in this paper will be enriched by adding modules such as the interbank market, the stock and bond markets (allowing agents to decide their portfolio allocation), and long-run growth factors (investment goods, heterogeneous worker skills, R&D investments, etc.).

References

[1] Adrian, T., Shin, H.S. (2008) "Liquidity, monetary policy and financial cycles", *Current Issues in Economics and Finance*, 14(1), Federal Reserve Bank of New York (January/February).

[2] Adrian, T., Shin, H.S. (2009), "Money, Liquidity, and Monetary Policy", *American Economic Review*, 99(2): 600-605.

[3] Adrian, T., Shin, H.S. (2010), "Liquidity and leverage", *Journal of Financial Intermediation*, 19(3): 418-437.

[4] Ballot G, Eliasson G., Taymaz E. (2006), "The Role of Commercialization Competence in Endogenous Economic Growth", *Working Paper, Schumepter society conference.*

[5] Ballot G, Taymaz E. (1998), "Human Capital, Technological Lock-in, and Evolutionary Dynamics", in: Eliasson G., Green C., *Microfoundations of Economic Growth, a Schumpeterian perspective*, The University of Michigan Press.

[6] Bennett R.L., Bergmann B.R. (1986), *A Microsimulated Transactions Model of the United States Economy*, John Hopkins University Press, Baltimore.

[7] Bergmann B.R. (1973), "Labor Turnover, Segmentation and Rates of Unemployment: A Simulation-Theoretic Approach. Project on the Economics of Discrimination", University of Maryland, *mimeo.*

[8] Bergmann B.R. (1974), "A Microsimulation of the Macroeconomy with Explicitely Represented Money Flows", *Annals of Economic and Social Measurement*, 3: 475-489.

[9] Booth L., Asli Demirgu-Kunt V.A., Maksimovic V. (2001), "Capital Structures in Developing Countries", *Journal of Finance*, 56(1): 87-130.

[10] Brock W.A. (1993), "Pathways to Randomness in the Economy: Emergent Nonlinearity and Chaos in Economics and Finance", *Estudios Economicos* 8: 3-55.

[11] Brunnermeier M.K., Pedersen L.H. (2009), "Market liquidity and funding liquidity", *Review of Financial Studies*, 22(6): 2201-2238.

[12] Cincotti S., Raberto M., Teglio A. (2010), "Credit money and macroeconomic instability in the agent-based model and simulator Eurace", *Economics - The Open-Access, Open-Assessment E-Journal*, Kiel Institute for the World Economy, 4(26).

[13] Cincotti S., Raberto M., Teglio A. (2012), "Debt Deleveraging and Business Cycles. An Agent-Based Perspective", *Economics - The Open-Access, Open-Assessment E-Journal*, Kiel Institute for the World Economy, 6(27).

[14] Dawid H., Neugart M. (2011), "Agent-Based Models for Economic Policy Design", *Eastern Economic Journal*, 37(1): 44-50.

[15] Deissenberg C., van der Hoog S., and Dawid H. (2008), "EURACE: A Massively Parallel Agent-based Model of the European Economy", *Applied Mathematics and Computation*, 204: 541-552.

[16] Delli Gatti D., Gallegati M., Kirman A. (2000), *Interaction and Market Structure. Essays on Heterogeneity in Economics*, Lecture Notes in Economics and Mathematical Systems, vol. 484, Springer Verlag. Berlin.

[17] Delli Gatti D., Di Guilmi C., Gallegati M., Gaffeo E., Giulioni G., Palestrini A. (2005), "A new approach to business fluctuations: heterogeneous interacting agents, scaling laws and financial fragility", *Journal of Economic Behavior and Organization*, 56(4): 489-512.

[18] Delli Gatti, D., Gallegati, M., Greenwald, B., Russo, A., and Stiglitz, J.E. (2009), Business Fluctuations and Bankruptcy Avalanches in an Evolving Network Economy, *Journal of Economic Interaction and Coordination* 4(2): 195-212.

[19] Delli Gatti D., Gallegati M., Greenwald B., Russo A., Stiglitz J.E. (2010), "The financial accelerator in an evolving credit network", *Journal of Economic Dynamics and Control*, 34(9): 1627-1650.

[20] Diamond D.W., Rajan R. (2000), "A Theory of Bank Capital", *Journal of Finance*, 55(6): 2431-2465.

[21] Donaldson G. (1961), "Corporate debt capacity: a study of corporate debt policy and the determination of corporate debt capacity", Harvard Business School, Harvard University.

[22] Dosi G., Fagiolo G., Roventini A. (2006), "An Evolutionary Model of Endogenous Business Cycles", *Computational Economics*, 27(1): 3-34.

[23] Dosi G., Fagiolo G., Roventini A. (2010), "Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles", *Journal of Economic Dynamics and Control*, 34(9): 1748-1767.

[24] Dosi G., Fagiolo G., Napoletano M., Roventini A. (2012), "Income Distribution, Credit and Fiscal Policies in an Agent-Based Keynesian Model", *LEM Papers Series* 2012/03, Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.

[25] Eliasson G. (1976), *Business Economic Planning – Theory, Practice and Comparison*, Wiley, London.

[26] Eliasson G. (1977), "Competition and Market Processes in a Simulation Model of the Swedish Economy", *American Economic Review*, 67: 277-281.

[27] Eliasson G. (1984), "Micro Heterogeneity of Firms and the Stability of Industrial Growth", *Journal of Economic Behavior and Organization*, 5(3-4): 249-274.

[28] Eliasson G. (1985), *The Firm and Financial Markets in the Swedish Micro-to-Macro Model - Theory, Model and Verification*, IUI, Stockholm.

[29] Eliasson G. (1991), "Modeling the Experimentally Organized Economy: Complex Dynamics in an Empirical Micro-Macro Model of Endogenous Economic Growth", *Journal of Economic Behavior and Organization*, 16: 153-182.

[30] Epstein J.M., Axtell R.L. (1996), *Growing Artificial Societies: Social Science from the Bottom Up*, MIT Press.

[31] Fagiolo G., Dosi G., Gabriele R. (2004), "Matching, Bargaining, And Wage Setting In An Evolutionary Model Of Labor Market And Output Dynamics", *Advances in Complex Systems*, 7(2): 157-186.

[32] Fagiolo G., Roventini, A. (2009), "On the Scientific Status of Economic Policy: A Tale of Alternative Paradigms", *The Knowledge Engineering Review*, 27(Special Issue 02): 163-185.

[33] Fagiolo G., Roventini, A. (2012), "Macroeconomic Policy in DSGE and Agent-Based Models", *SSRN Working Paper Series*, URL: $http://ssrn.com/abstract = 2011717$.

[34] Flannery M.J. (1994), "Debt Maturity and the Deadweight Cost of Leverage: Optimally Financing Banking Firms", *American Economic Review*, 84(1): 320-31.

[35] Flannery M.J., Rangan K.P. (2006), "Partial Adjustment Toward Target Capital Structures", *Journal of Financial Economics*, 79(3): 469-506.

[36] Föllmer H. (1974), "Random Economies with Many Interacting Agents", *Journal of Mathematical Economics*, 1: 51-62.

[37] Fostel A., Geanakoplos J. (2008), "Leverage Cycles and the Anxious Economy", *American Economic Review*, 98(4): 1211-44.

[38] Frank M.Z., Goyal V.K. (2008), "Tradeoff and Pecking Order Theories of Debt", in: Espen Eckbo (ed.) *The Handbook of Empirical Corporate Finance*, Ch. 12: 135-197.

[39] Gaffeo G., Delli Gatti D., Desiderio S., Gallegati M. (2008), "Adaptive Microfoundations for Emergent Macroeconomics", *Eastern Economic Journal*, 34(4): 441-463.

[40] Gallegati M., Kirman A. (1999), *Beyond the Representative Agent*, Edward Elgar, Northampton.

[41] Geanakoplos J. (2010), "Leverage Cycle", *Cowles foundation Paper* No. 1304, Yale University.

[42] Godley W., Lavoie M. (2006), *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth*, Palgrave MacMillan.

[43] Graham J.R., Harvey C. (2001), "The Theory and Practice of Corporate Finance", *Journal of Financial Economics*, 60: 187-243.

[44] Greenlaw D., Hatzius J., Kashyap A.K., Shin H.S. (2008), "Leveraged Losses: Lessons from the Mortgage Market Meltdown", *Proceedings of the U.S. Monetary Policy Forum.*

[45] Gropp R., Heider F. (2010), "The Determinants of Bank Capital Structure", *Review of Finance*, 14(4): 587-622.

[46] Haber G. (2008), "Monetary and Fiscal Policy Analysis with an Agent-Based Macroeconomic Model", *Jahrbücher für Nationalökonomie und Statistik*, 228: 276-295.

[47] He Z., Khang I.G., Krishnamurthy A. (2010), "Balance Sheet Adjustments in the 2008 Crisis", *IMF Economic Review*, 58: 118-156.

[48] Hovakimian A., Opler T., Titman S. (2001), "The Debt-Equity Choice", *Journal of Financial and Quantitative Analysis*, 36: 1-24.

[49] Howitt P., Clower R. (2000), "The Emergence of Economic Organization", *Journal of Economic Behavior and Organization*, 41: 55-84.

[50] Jensen M.C., Meckling W.H. (1976), "Theory of the Firm: Managerial Behavior, Agency Costs, and Ownership Structure", *Journal of Financial Economics*, 3: 305-360.

[51] Kalemli-Ozcan S., Sorensen B., Yesiltas S. (2011), "Leverage Across Firms, Banks, and Countries", *NBER Working Papers* 17354.

[52] Kinsella S., Greiff M., Nell E. (2011), “Income Distribution in a Stock-Flow Consistent Model with Education and Technological Change”, *Eastern Economic Journal*, 37(1): 134-149.

[53] Kirman A. (1991), “Epidemics of Opinion and Speculative Bubbles in Financial Markets”, in: Taylor M. (ed.), *Money and Financial Markets*, Macmillan.

[54] Kirman A. (1992), “Whom or What Does the Representative Individual Represent?”, *Journal of Economic Perspectives*, 6: 117-136.

[55] Kirman A. (1993), “Ants, Rationality and Recruitment”, *Quarterly Journal of Economics* 108: 137-156.

[56] Kirman A. (1999), “Aggregate Activity and Economic Organisation”, *Revue Européene des Sciences Sociales*, XXXVII(113): 189-230.

[57] LeBaron B., Tesfatsion L.S. (2008), “Modeling Macroeconomies as Open-Ended Dynamic Systems of Interacting Agents”, *American Economic Review*, 98(2): 246-250.

[58] Lemmon M., Roberts M., Zender J. (2008), “Back to the beginning: Persistence and the cross-section of corporate capital structure”, *Journal of Finance*, 63: 1575-1608.

[59] Mehrotra V., Mikkelsen W., Partch M. (2003), “Design of Financial Policies in Corporate Spinoffs”, *Review of Financial Studies*, 16: 1359-1388.

[60] Myers, S.C. (1977), “Determinants of corporate borrowing”, *Journal of Financial Economics*, 5(2): 147-175

[61] Myers S.C., Majluf N.S. (1984), “Corporate Financing and Investment Decisions When Firms Have Information that Investors Do Not Have”, *Journal of Financial Economics*, 13: 87-224.

[62] Neugart M. (2008), “Labor Market Policy Evaluation with ACE”, *Journal of Economic Behavior and Organization*, 67(2): 418-430.

[63] Neugart M., Richiardi M. (2012), “Agent-based models of the labor market”, *Working Paper* No. 125, LABORatorio Revelli - Center for Employment Studies, Torino.

[64] Orcutt G.H. (1957), “A New Type of Socio Economic System”, *Review of Economics and Statistics*, 58: 773-797.

[65] Rajan R., Zingales L. (1995), “What do we know about capital structure? Some evidence from international data”, *Journal of Finance*, 50: 1421-1460.

[66] Riccetti L., Russo A., Gallegati M. (2013), "Leveraged Network-Based Financial Accelerator", *Journal of Economic Dynamics and Control*, 37(8): 1626-1640.

[67] Russo A., Catalano M., Gaffeo E., Gallegati M., Napoletano M. (2007), "Industrial dynamics, fiscal policy and R&D: Evidence from a computational experiment", *Journal of Economic Behavior & Organization*, 64(3-4): 426-447.

[68] Seppecher P. (2012), "Flexibility of wages and macroeconomic instability in an agent-based computational model with endogenous money", *Macroeconomic Dynamics*, 16(s2): 284-297.

[69] Tesfatsion L.S., Judd K.L. (2006), *Handbook of Computational Economics: Agent-Based Computational Economics*, Vol. 2, North-Holland.

[70] Wertheimer R., Zedlewski S.R., Anderson J., Moore K. (1986), "DYNASIM in comparison with other microsimulation models", in: Orcutt G.H., Merz J., Quinke H. (eds.), *Microanalytic Simulation Models to Support Social and Financial Policy*, North-Holland, Amsterdam.

[71] Westerhoff F. (2008), "The Use of Agent-Based Financial Market Models to Test the Effectiveness of Regulatory Policies", *Jahrbücher für Nationalökonomie und Statistik*, 228: 195-227.

[72] Westerhoff F., Franke R. (2012), "Agent-Based Models for Economic Policy Design: Two Illustrative Examples", *BERG Working Paper*, 88, University of Bamberg.