An Agent-Based Decentralized Matching Macroeconomic Model

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Abstract

In this paper we present a macroeconomic microfounded framework with heterogeneous agents – households, 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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JEL classification codes: E32, C63.

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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 start from simple (adaptive) individual behavioral rules and interaction mechanisms 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).
We report a few examples about agent-based models which analyze a decentralized matching mechanism in one or more markets in order to reproduce some macroeconomic emergent features. 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. 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. 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. 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).

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 - households, firms, banks - interacting in four markets - goods, labour, 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 micro-founded 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. 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). Geanakoplos (2010) finds that leverage is pro-cyclical, while Kalemli-Ozcan et al. (2011), as well as Adrian and Shin (2008,2009), find that the leverage pattern for non-financial firms is acyclical (instead this is pro-cyclical for investement 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 emerged 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. (2011) 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.
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.

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 composes 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. Section 8 concludes.

2 Model setup

The macroeconomy is populated by households ($h = 1, 2, ..., H$), 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 households.
- Goods market: households and firms.
- Deposit market: banks and households.

Agents are boundedly rational and follow (relatively) simple rules of behaviour in an incomplete and asymmetric information context: households 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 households (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); households' saving goes into bank deposits; given the Basilea-like regulatory constraints, banks extend credit to finance firms' production; firms choose the banks offering lowest interest rates, while households 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. Households decide their desired consumption on the basis of their wages and wealth (net of taxes).

9. Households and firms interact in the goods market. As a result, some households 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. Households 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 households.

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

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 subtract from households' wealth. In the case private wealth is not enough, then government intervenes.

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, households 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 h_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 h_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[1], $\hat{y}_{ft-1}$ 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}.

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):

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

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

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:

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

where i_{CBt} 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 $\Gamma^d_{bt} = \bar{k}_{bt} - B_{bt}$. 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.

3.2 Labor market

In each period, the government hires a fraction g of households. The remaining part is available for working in the firms. Firm's f labor demand depends on the total capital available: $A_{ft} + B_{ft}$. Each worker posts a wage w_{ht} which is updated according to the following rule:

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

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

Given this setting on labor supply and demand, firms and households interact according to the matching mechanism. As a consequence, each firm ends up with a number of workers

n_{ft} and a residual cash (insufficient to hire an additional worker). Obviously, a fraction of households 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 households represent the demand side, while firms are the supply side. Households set the desired consumption as follows:

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

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_{ht}. If the amount c^d_{ht} is smaller than the average price of one good $\bar{p}$ then $c^d_{ht} = min(\bar{p}\,, w_{ht} + A_{ht})$. By summing up the individual consumption of households 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, households and firms interact according to the matching mechanism. As a consequence, each household 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 households are on the supply side. Banks offer an interest rate on deposits according to their funds requirement:

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

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 viceversa. However, the interest rate on deposits can increase till a maximum given by the policy rate r_{CBt} which is both the rate at which banks could refinance from the central bank and the rate paid by the government on public bonds.

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

$$i_{ht}^D = \begin{cases} i_{ht-1}^D \cdot (1 - \alpha \cdot U(0,1)), & \text{if } D_{ht-1} = 0 \\ i_{ht-1}^D \cdot (1 + \alpha \cdot U(0,1)), & \text{if } D_{ht-1} > 0 \end{cases} \quad (11)$$

where D_{ht-1} is the household h's deposit in the previous period. This means that a household 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 hypothesize that a household deposits all the available money in a single bank that offers an adequate interest rate. A household that decides to not deposit her money in a bank signals a preference for liquidity, because 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:

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

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 will be subtracted from 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:

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

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 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:

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

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 subtracted from 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 viceversa.

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. Households 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 Households

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

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

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_{ht} is the wage gained by employed workers, div_{ht} is the fraction (proportional to the household h's wealth compared to overall households' 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_{ht} represents interests on deposits, and $c_{ht} \leq c^d_{ht}$ is the effective consumption. Households 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_{CBt} 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

Table 1: Parameter setting

H	number of households	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

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 analyse the results for the last 50 (so the first 100 are used to initialise 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_{CBt} 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 unemploymet rate and the firms' profit rate.[2] First of all, there is a high positive

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

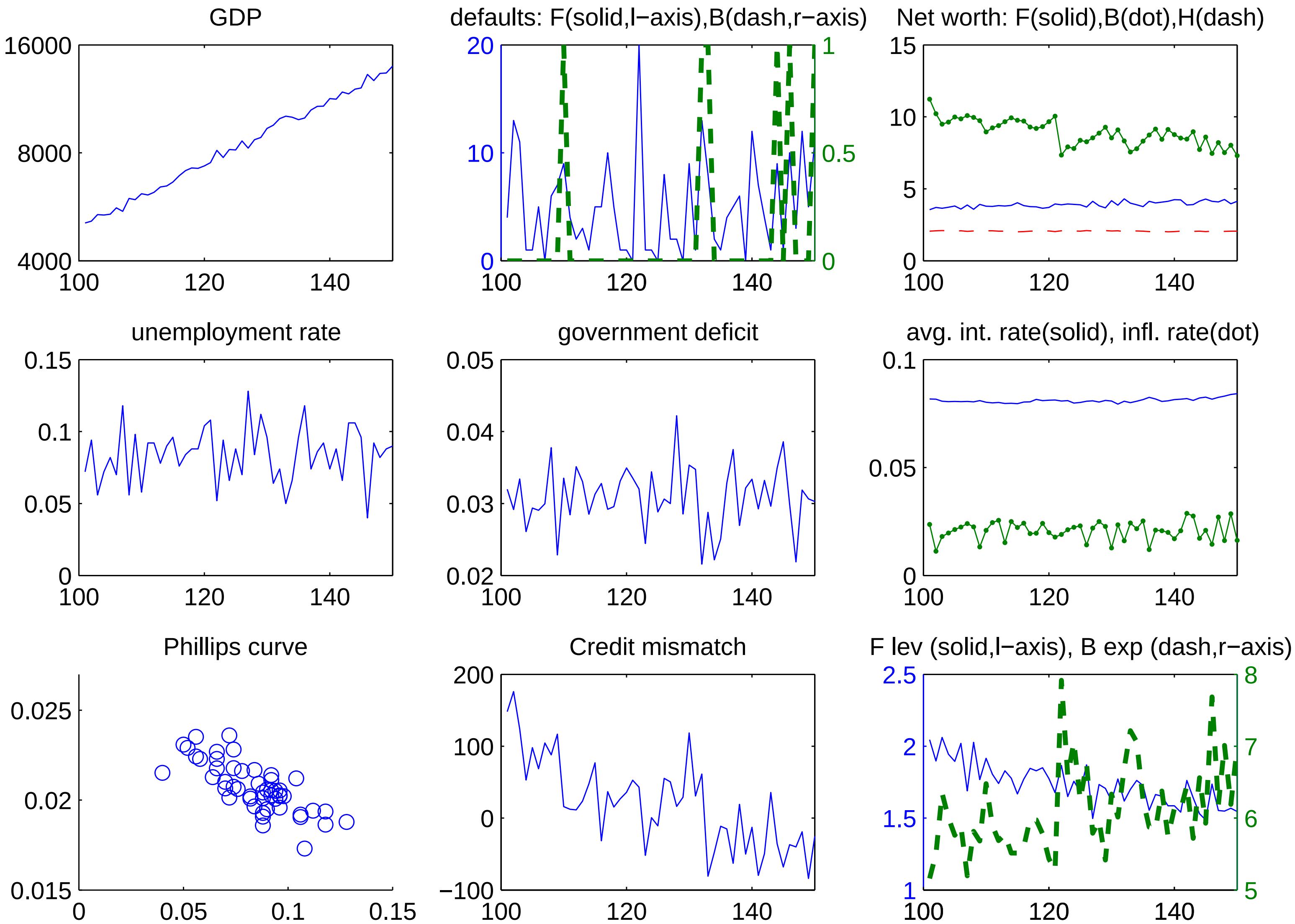
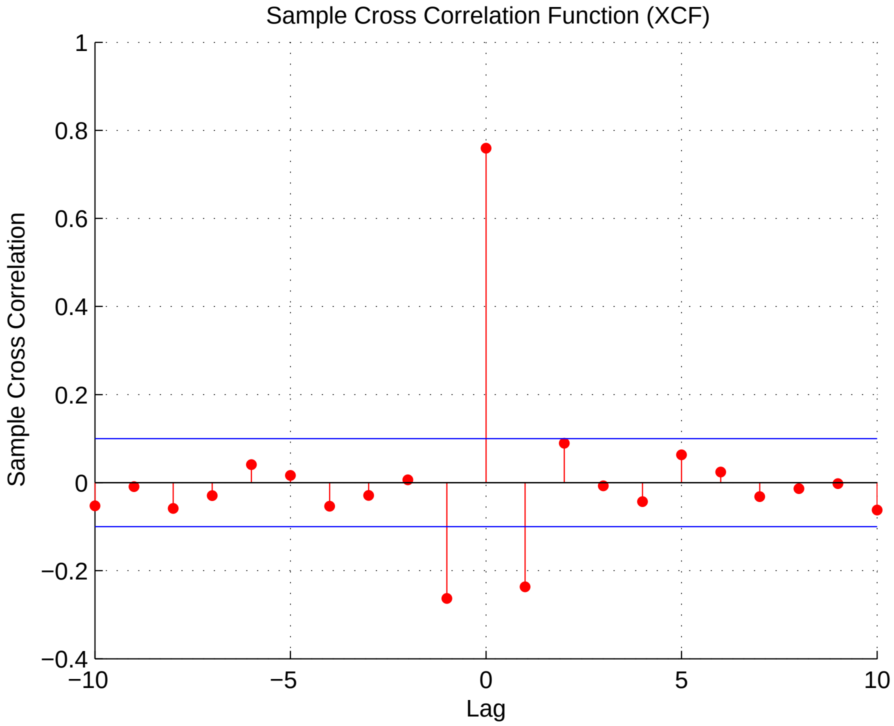


Figure 1: Baseline model: Simulation results

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 households' 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 expansion of the economy and then a fall of the unemployment rate follows. 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 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, that 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 capitalised 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 capitalised they

Figure 2: Unemployment rate and firms' profit rate.



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 households 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%).

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

7.1 Financial factors and the real economy

Now we analyse 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).

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

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,

Figure 3: Firm leverage and unemployment rate.

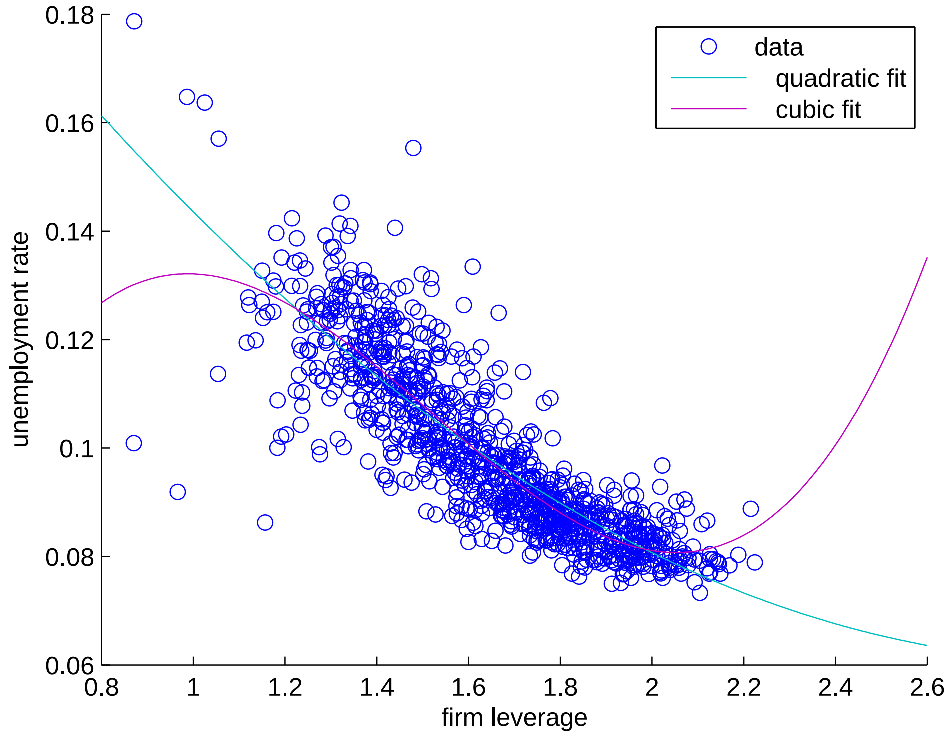
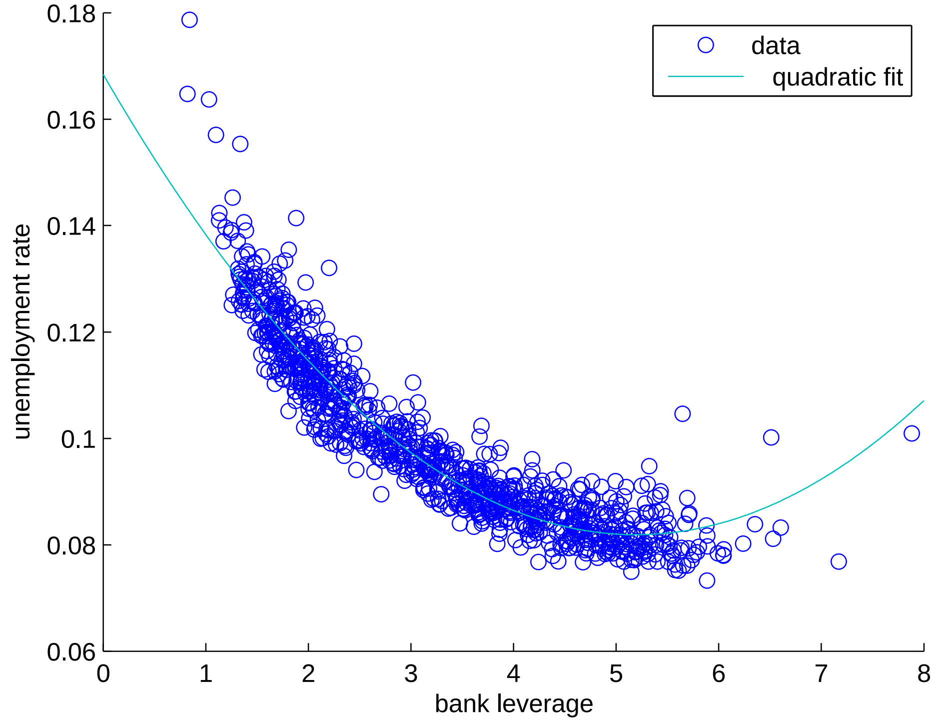


Figure 4: Bank exposure and unemployment rate.



the latter hire more workers and the unemployment rate decreses. But, when the exposure of banks becomes "excessive" this leads to instability (more failures) and an increase of the unemployment rate follows.

7.2 Large crises

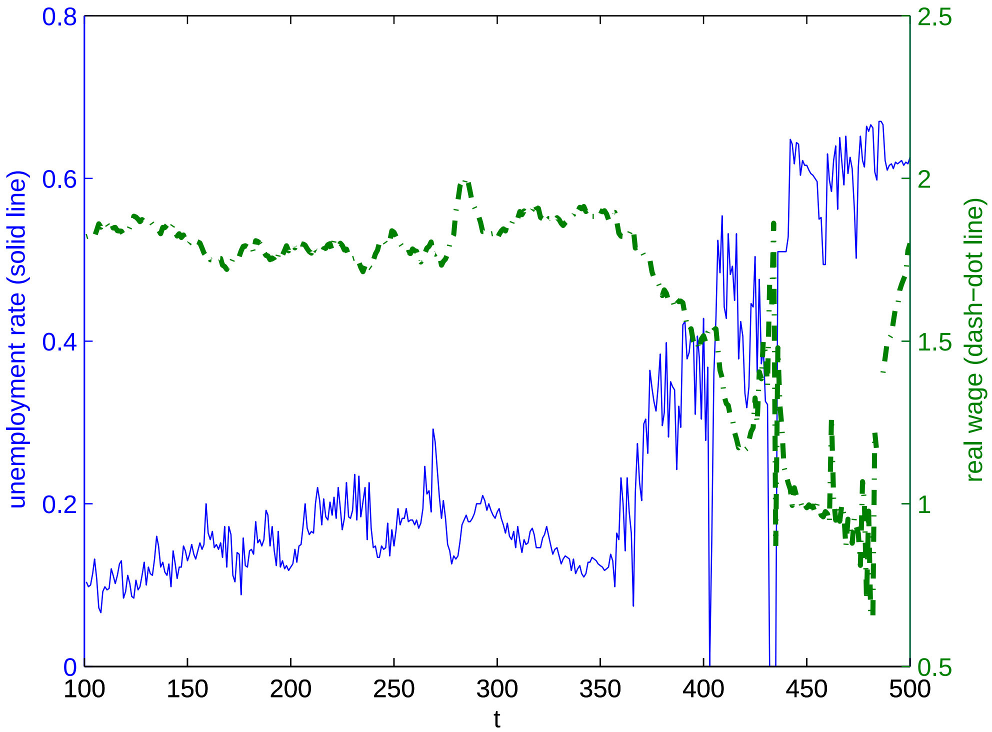
In the previous Monte Carlo experiment we observe 5 out of 1000 cases characterised by a large mean unemployment rate (during the period from $t = 101$ to $t = 150$). This means that large crises can appear in the macroeconomic system. Moreover, in some simulations we note that the time series of the 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).
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 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 Concluding remarks and future research

We present an agent-based macroeconomic model in which heterogeneous agents (households, 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

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



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.

Monte Carlo simulations show that model findings are quite robust. A particularly relevant result is that a non-linear relation between firm leverage and unemployment emerges: 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 the negative relation with the unemployment rate tends to reverse. Also bank exposure and unemployment are non-lineraly related: for low levels, an increase of bank exposure reduces the rate of unemployment; instead, for high levels of bank 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 decreses. 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, firm leverage and bank exposure may support the working of the economy (reducing the unemployment rate), but when the levels of both leverage or 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 in a situation, without the possibility to spontaneously recover unless an exogenous intervention.

Our modeling framework can be useful to understand the effects of some policy or institutional changes. Indeed, in future developments we will analyse the sensitivity of simulations 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, heterogeneous consumption behavior, etc. Finally, the baseline model presented in this paper will be enriched by adding modules as the interbank market, the stock and bond markets (allowing agents to decide their portfolio allocation), and long-run growth factors (heterogeneous workers’ 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] Booth L., Asli Demirgu-Kunt V.A., Maksimovic V. (2001), “Capital Structures in Developing Countries”, *Journal of Finance*, 56(1): 87-130.

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

[6] 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).

[7] 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).

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

[9] 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.

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

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

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

[13] 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.

[14] 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.

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

[16] 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.

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

[18] Flannery M.J., Rangan K.P. (2006), "Partial adjustment toward target capital structures", *Journal of Financial Economics*, 79(3): 469-506.

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

[20] 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.

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

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

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

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

[25] 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.*

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

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

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

[29] 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.

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

[31] 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.

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

[33] 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.

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

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

[36] 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.

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

[38] Riccetti L., Russo A., Gallegati M. (2011), "Leveraged Network-Based Financial Accelerator", *Quaderno di Ricerca* 371, Department of Economics and Social Sciences, Università Politecnica delle Marche.

[39] 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.

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

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