Agent Based-Stock Flow Consistent Macroeconomics: Towards a Benchmark Model

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Abstract

The global financial crisis has forced standard macroeconomics to re-examine the plausibility of its assumptions and the adequacy of the policy prescriptions flowing from those assumptions. We believe a renewal of macroeconomic thinking and macroeconomic modeling is possible by recognizing that our economies should be analyzed as complex adaptive systems. A coherent and exhaustive representation of the inter-linkages between the real and financial sides of the economy is vital as well. We propose a macroeconomic framework based on a novel combination of the Agent Based and Stock Flow Consistent approaches. This paper presents a benchmark model for this innovative approach. Our model depicts an economy with capital and credit in which different types of agents locally interact on different markets. We provide a detailed representation of individual agents' balance sheets, ensuring the model accounting consistency at the micro, meso, and macro levels. We analyze the properties of our simulated economy under different configurations of agent heuristics, focusing in particular on the role of credit and investment. We explain in detail the logic followed to calibrate and validate the model. Results show that our benchmark model is able to reproduce many stylized facts observed in real world, thus representing a good starting point to test - in the next works - different economic policies and institutional setups. Finally, the relatively simple and flexible structure of the model opens up many possibilities for development of the framework along different lines, thus providing a fertile soil for new applications.

Keywords: Agent Based Macroeconomics, Stock Flow Consistent Models, Business Cycles, Crisis. JEL Codes: E03, E32, O30

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1 Introduction

More than seven years since the onset of the global financial crisis, we are still assessing how the crisis should change our views about macroeconomic policy. The crisis has cast doubt on the ability of standard macroeconomic models - in particular of Real Business Cycle and New-Keynesian dynamic stochastic general equilibrium (DSGE) models - to explain the functioning of our economic systems and, perhaps more importantly, to provide adequate advice on appropriate stabilization policies to prevent the occurrence of large-scale economic turmoil and tackle its consequences. As pointed out by (Blanchard et al., 2012, p.57):

The workhorse New Keynesian dynamic stochastic general equilibrium (DSGE) models on which we were concentrating so much of our attention have been of minimal value in addressing the greatest macroeconomic crisis in three-quarters of a century.

The DSGE community responded to the crisis¹ with new models embedding some types of financial frictions. Despite this, we feel that standard macroeconomics is still far from having taken the lessons of the crisis on board. Our contribution goes beyond mainstream models in developing a relatively simple, general, and flexible model based on the following conceptual pillars.

Micro- and macro-economics are different. The representative agent approach is inherently affected by the fallacy of composition in assuming that what is true for individual agents is also valid for the whole economic system. We believe on the contrary the correct way of linking the micro, meso, and macro layers of the economy should be geared around the concept of complex adaptive systems, showing independent system-wide properties "emerging" from agents' disperse interactions (Delli Gatti et al., 2010a).

Agents are not fully rational nor fully informed. The decision-making process by agents is characterized by the prevalence of "satisficing" behaviors over "optimizing" ones, due to the presence of informational and computational limitations (Simon, 1955, 1976). Adaptivity and heterogeneity of agents' beliefs and heuristics should be a key ingredient to evaluate the effects of alternative policy formulations (Anufriev et al., 2013).

The real and financial sides of the economy are closely interrelated. Every macroeconomic model designed to perform fiscal and monetary policy analysis cannot abstract from a proper representation of the financial system and the process by which "inside" money (i.e. money issued by private intermediaries in the form of debt) and "outside" money (i.e. government-issued money) are created, injected in the monetary circuit, and destroyed.

Every macroeconomic model should provide a complete and coherent accounting system at both the individual and aggregate levels. Economic agents are connected to each other through the stocks they hold in their balance sheets, either as assets or as liabilities. Decisions undertaken by individual agents and resulting in a variation of their balance sheet affect other agents' balance sheets both directly and indirectly. In order to track these effects and avoid having black holes in the accounting framework, every financial stock should then be recorded as an asset for someone and a liability for someone else. Similarly, every flow should be an inflow for someone and an outflow for someone else.

In order to embed these features in our model, we combine the bottom-up perspective characterizing the Agent Based (AB) modeling approach (Farmer and Foley, 2009; Esptein, 2006), with the rigorous accounting framework which we find at the base of the Stock-Flow Consistent (SFC) framework (Godley and Lavoie, 2007).

In this way we aim to provide a rigorous and realistic benchmark model to assess the effects of different economic policies. The rigor of our analysis requires some preliminary steps to be made before the model can be used for this purpose. These steps are aimed at improving our understanding of the functioning of the model, identifying the underlying dynamics, and investigating its properties under different circumstances.

In the present work we provide a detailed discussion of the logic followed to calibrate the model parameters and set the initial values of stocks and flows in a consistent way; we analyze the dynamics of the model under the baseline scenario; we compare the properties of our artificial time series with real world ones to assess whether the model provides an acceptable approximation of reality; finally, we perform sensitivity experiments on some relevant behavioral parameters to check the robustness of our results and to investigate the properties of our simulated economy as a result of different behavioral specifications.

Our artificial time series are analyzed by separating the cyclical and trend components. The model shows how heterogeneity endogenously emerges, starting from initial symmetric conditions, leading to

¹See for example Borogan Aruoba et al. (2013); Andreasen et al. (2013); Andreasen (2013); Benes et al. (2014)

interesting dynamics and changing market structures. Our results show that the model generates persistent economic fluctuations whose properties are similar to those observed in real world data. The model is also capable of replicating several other stylized facts concerning, for example, the distribution of firms' size and banks' credit degree distribution. The analysis of the long term dynamics highlights that, under the majority of cases analyzed, the economy tends to converge to what we defined as a quasi steadystate, that is a temporarily stable configuration in which real aggregates trends are fluctuating around a steady level, and nominal variables growth rates fluctuates around constant values, and inter-sectoral flows and stock-flow ratios tend to stabilize. These outcomes will be the starting point to perform policy and scenario analysis in further publications.

The rest of the paper is organized as follows: in the next section we briefly discuss the literature which constitutes the background of the present work, highlighting similarities and divergences, and stressing the potential benefits arising from the combination of the Agent Based and Stock Flow Consistent approaches. In section **3** we sketch out the basic structure of the model, the sequence of events taking place within each round of the simulation, and the features of the matching mechanism adopted on our simulated markets. Section **4.1** presents the behavioral equations of consumption and capital good producers. Section **4.2** instead presents the heuristics followed by banks, with a particular focus on their credit supply function. The causes and consequences of firms' and banks' failures are treated in section **4.3**, while section **5** we explain the logic adopted to setup the simulations while section **6** discusses the results of our simulations and the properties of our simulated economy. In the conclusion we discuss the open issues of our research and briefly schedule future works.

2 Related literature

Several authors have advocated increasing investment in agent-based modeling in response to the crisis (Farmer and Foley, 2009), (Colander et al., 2009). The agent-based approach is rooted in the conception of the economy as a complex adaptive system composed of heterogeneous, boundedly rational agents, interacting locally in a given institutional framework (see Esptein (2006) for a general discussion of the methodology). Contributions in this field highlight how even the simplest microeconomic behaviors may lead to complex systemic properties due to feedbacks, externalities, and other structural effects arising from agents disperse interactions. For example, Brock and Hommes (1997) focuses on the heterogeneity of agents' beliefs and selection mechanisms of agents' heuristics to explain the convergence towards well-behaved equilibria, or the emergence of chaotic dynamics in financial markets. Along the same path, Chiarella and He (2001) incorporated in an equilibrium model the interactions of heterogeneous agents in financial markets, showing how the resulting dynamical system for asset price and wealth turned out to be non-stationary.

Empirically, agent based macroeconomic models are capable of reproducing a significant number of micro and macroeconomic stylized facts (see, for example, Dosi et al., 2010, 2013, 2015; Delli Gatti et al., 2008; Assenza et al., 2015; Riccetti et al., 2014), often outperforming DSGE models (Fagiolo and Roventini, 2012). In particular, Agent Based models have proven to be well-suited to explain the emergence of financial fragility. Much attention has been devoted to the analysis the impact exerted on business cycles by credit conditions and firms' finance, in a context of incomplete asymmetric information and imperfect financial markets (Greenwald and Stiglitz, 1993). Good examples of this field of research are Delli Gatti et al. (2005, 2008, 2010b) who focused on the role of commercial and banks' credit networks topology in spreading financial fragility through contagion effects.

Similarly, Cincotti et al. (2010) investigates the link between business cycles and monetary aggregates, finding that the amplitude of business cycles is greater the more firms resort to external finance, rather than internal funding. Using the same model, Raberto et al. (2012) show that debt dynamics plays a key role in shaping business cycles dynamics: exogenous changes to the regulatory capital requirement foster higher indebtedness which generates boom and burst dynamics.

Our attention is not limited to the agent-based literature. We point to the so called flows-of-funds approach Godley and Cripps (1983) which aims at providing a comprehensive and fully integrated representation of the economy, including all financial transactions. Using flow of funds accounts to analyze the US economy at the turn of the century, Godley and Wray (1999); Godley and Zezza (2006) pointed out that growing households' indebtedness was pushing assets' inflation and leavening systemic risk under the surface of the alleged stability of the early '00s, thereby anticipating the crisis with significant precision regarding the timing and mechanics of the collapse.

In 2011, the Bank of England used a flow-of-funds approach to analyze the mechanics of financial

instability. Barwell and Burrows (2011) advocated the diffusion of macroeconomic approaches that stress the importance of balance sheet linkages in spotting buildups of financial fragility. Stock Flow Consistent (SFC hereafter) models, stemming from Godley's earlier work, aim at responding to this call (Godley, 1997; Godley and Lavoie, 2007). The objective of the SFC framework is to provide a comprehensive and fully integrated representation of the real and financial sides of the economy through the adoption of rigorous accounting rules based on the quadruple entry principle developed by Copeland (1949). This approach employs specific social accounting matrices to track the variation of financial stocks and flows, and to ensure that every financial stocks or flow in the economy is recorded as a liability or outflow for someone and an asset or inflow for someone.²

Our feeling is that AB models may greatly benefit from an integration with the SFC accounting framework. As noted by (Bezemer, 2012, p.18)

... complex behaviors and sudden transitions also arise from the economy's financial structure

as reflected in its balance sheets.

We feel that a fusion of the two approaches has the potential to set an alternative paradigm to economic modeling, as advocated by Farmer and Foley (2009); Delli Gatti et al. (2010a).

AB models can help to overcome many of the limitations of the SFC approach (Kinsella, 2011). For example, SFC models are traditionally highly aggregated, dividing the economy in major institutional sectors, typically households, banks, firms, and the public sector.³ This perspective usually abstracts from tracking intra-sectoral flows and does not allow to analyze the causes and effects of agents' heterogeneity emerging within and across sectors. This limit definitively hinders, and in some cases impedes, the possibility of studying phenomena which are deeply connected to agents' heterogeneity and agents' disperse interaction, such as self-organization processes within markets or industries, and the generation of financial bubbles,

To our knowledge, the economic literature provides just one other example of AB model implementing SFC starting from the very bottom layer, represented by individual agents' balance sheets: the EURACE model (see Deissenberg et al., 2008; Cincotti et al., 2010; Raberto et al., 2012; Dawid et al., 2012, 2014; van der Hoog and Dawid, 2015), a massively large-scale economic model of the EU economy first developed in 2006 and now implementing many hyper-realistic features such as day-by-day interactions, asynchronous decisions, different frequencies of economic processes, geographical space, and a huge variety of agents, including even international statistical offices. Although our work shows several points of convergence with the philosophy of the EURACE project, our objective is different and somehow complementary.

Our work started from the consideration that, although a few attempts to develop AB-SFC models exist in the literature (Kinsella et al., 2011; Riccetti et al., 2014; Seppecher, 2012), we have not yet a well-defined set of concepts, rules and tools to develop these models. A similar criticism may partially apply also the EURACE model, as its main strengths also tend to limit its accessibility and re-usability by other scholars. The number of complex features implemented in the EURACE model may make it difficult for those who are not directly involved in its development to enter the logic of the model, let alone master the skill required to manage it, and adapt it for new purposes. Furthermore, running such a large model necessitates the use of massively parallel computing clusters, which are not generally available to all scholars.

Our objective differs in that we do not want to move towards a one-to-one matching of real economies, but rather we aim to develop a relatively simple and flexible AB-SFC model to study policies and institutional setups to steer economic cycles and tackle economic instability. Our contribution aspires to serve as a benchmark for all scholars in the AB and SFC communities, as well as from other modeling traditions, who want to get involved in this approach.⁴.

 $^{^{2}}$ By looking at the evolution of aggregate inter-sectoral flows and stock-flow norms, one can then get a first clue of the possible emergence of imbalances in the stocks accumulation between sectors, eventually leading to crisis if not properly tackled.

 $^{^{3}}$ See Caverzasi and Godin (2015) for a recent survey of the SFC literature.

⁴Our model has been developed using our brand new Java Macro Agent Based (JMAB) programming tool suite, explicitly designed for AB-SFC models. The platform exploits the logic of the object-oriented programming paradigm to provide a flexible and highly modular computational framework embedding general procedures to ensure and check the model stock-flow consistency at the macro, meso and micro levels. It has the potential to implement a wide variety of models and a number of crucial features of modern economic systems, in particular regarding the handling of heterogeneous real and financial stocks in agents' balance sheets (see for example section 4.2) and the representation of commercial and financial networks.

3 The model



Figure 1: Flow Diagram of the model. Arrows point from paying sectors to receiving sectors.

The economy described by the flow diagram of figure 1 is composed of various groups, or sectors, of boundedly rational agents, following simple heuristics in a context of incomplete and asymmetric information. More precisely, the model contains:

- A collection Φ_H of households selling their labor to firms in exchange for wages, consuming and saving in the form of banks' deposits. Households own firms and banks proportionally to their wealth, and receive a share of firms' and banks' profits as dividends. Unemployed workers receive a dole from the government. Finally, households pay taxes on their gross income.
- Two collections of firms: consumption (Φ_C) and capital (Φ_K) firms. Consumption firms produce a homogeneous consumption good using labor and capital goods manufactured by capital firms. Capital firms produce a homogeneous capital good characterized by the binary $\{\mu_k, l_k\}$, indicating respectively the capital productivity and the capital-labor ratio. Firms may apply for loans to banks in order to finance production and investment. Retained profits are held in the form of banks' deposits.
- A collection Φ_B of banks, collecting deposits from households and firms, granting loans to firms, and buying bonds issued by the Government. Mandatory capital and liquidity ratios constraints apply. Banks may ask for cash advances to the Central Bank in order to restore the mandatory liquidity ratio.
- A Government sector, which hires public workers (a constant share of the workforce) and pay unemployment benefits to households. The government collects taxes and issues bonds to cover its deficits.

• A Central Bank, which issues legal currency, holds banks' reserve accounts and the government account, accommodates banks' demand for cash advances at a fixed discount rate, and possibly buy government bonds which have not been purchased by banks.

3.1 Dispersed interactions

During each period of the simulation agents interact on five markets:

- A consumption goods market: households interact with consumption firms;
- A capital goods market: consumption firms interacts with capital firms;
- A labor market: households interact with government and both types of firms;
- A credit market: firms interact with banks;
- A deposit market: households and firms interact with banks.

Following Riccetti et al. (2014), we explicitly model agents' dispersed interactions by assuming that agents on the demand and supply sides of each market interact through a common matching protocol. In each period of the simulation, 'demand' agents are allowed to observe the prices or the interest rates charged by a random subset (whose size depends on a parameter χ proxying the degree of imperfect information) of potential suppliers. They choose the 'best' one: the cheapest counterpart for goods, labor, or credit markets, or the bank offering the highest interest rate for the deposit market. Each agent then has a probability of switching (Pr_s) from the previous supplier to the new one defined as follows (Delli Gatti et al., 2010a). For the consumption, capital, and credit markets, where prices (or interest rates) express a disbursement from the demander, the probability of switching to the new partner is decreasing (in a non-linear way) with the difference between p_{old} and p_{new} :

$$Pr_s = \begin{cases} 1 - e^{\epsilon(p_{new} - p_{old})/(p_{new})} & \text{if } p_{new} < p_{old} \\ 0 & \text{otherwise} \end{cases}$$
(3.1)

On the deposit market, interest rates generates an income for the depositor, the probability of switching is thus:

$$Pr_{s} = \begin{cases} 1 - e^{\epsilon(p_{old} - p_{new})/(p_{old})} & \text{if } p_{new} > p_{old} \\ 0 & \text{otherwise,} \end{cases}$$
(3.2)

where $\epsilon > 0$ is an exogenous parameter.

In some cases, some suppliers exhaust inventories available for sale, possibly leaving some customers with a positive residual demand. We then allow demand agents to look for other suppliers within the original random subset of potential partners in order to fulfil it. Markets interactions are 'closed' when demand agents have fulfilled their demand, when there are no supply agents willing or able to satisfy their demand, or if demanders run out of deposits to pay for demanded goods.

3.2 Sequence of events

In each period of the simulation, the following sequence of events takes place:

- 1. *Production planning*: consumption and capital firms compute their desired output level based on their sales expectations (sec: 4.1.1).
- 2. *Firms' labor demand*: firms evaluate the number of workers needed to produce the desired level of output (sec: 4.1.1).
- 3. *Prices, interest, and Wages*: consumption and capital firms set the price of their output while banks determine the interest rate on loans and deposits (sec: 4.1.2 and 4.2). Workers adaptively revise their reservation wages (sec: 4.4).
- 4. *Investment in capital accumulation*: consumption firms' determine their desired rate of capacity growth and, as a consequence, their real demand for capital goods
- 5. Capital good market first interaction: consumption firms interact with capital firms and choose their prefered supplier.

- 6. *Credit demand*: firms assess their demand for credit based on their expected financial requirement and their available internal funds.
- 7. *Credit market*: interaction takes place on the credit market. Banks evaluate each loan request and decide whether to grant the whole amount, a share of it, or nothing. The loan creation process leads to an expansion of the banks' balance sheets, as the new loan recorded as an asset is mirrored by a new deposit, a liability for the bank.
- 8. Labor market interactions: unemployed workers interact with firms on the labor market (sec: 4.5).
- 9. Production: capital and consumption firms produce their output.
- 10. Capital goods market second interaction: consumption firms purchase capital goods from their prefered supplier. Newly purchased machineries can be employed in the production process starting from the next period.
- 11. Consumption goods market: households decide how much to consume depending on their expected real disposable income and expected real wealth, with fixed propensities (sec: 4.4).
- 12. Interest, bonds and loans repayment: firms pay interest on loans and repay a (constant) share of each loan principal (sec: 4.1.6). The government repays bonds and interest to bonds' holders. Banks pay interest on deposits. If in the previous period they asked for cash advances to the Central Bank, they repay this amount plus a fixed exogenous interest.
- 13. Wages and dole: wages are paid to employed workers. Workers who are not employed receive a dole from the government.
- 14. *Taxes*: taxes on profits (of firms and banks) and income (of households) are paid to the government (sec: 4.1.6).
- 15. *Dividends*: a constant share of net-profits realized by banks and firms are distributed to households proportionally to their net wealth.
- 16. Deposit market interaction: households an firms decide in which banks to deposit their savings
- 17. Bond purchases: the government issues new bonds to cover any deficit between expenditure and revenues (sec: 4.5). We assume the interest rate on bonds and their price to be fixed. Banks use part of their reserves to buy bonds. The Central Bank buys all residual bonds.
- 18. *Cash Advances*: banks may ask the Central Bank for cash advances in order to respect the mandatory reserve ratio.

In each period of the simulation, firms may default when they run out of liquidity to pay wages or to honor the debt service while banks default if their net wealth turns negative. The effects of firms' and banks' defaults are treated in section 4.3.

4 Agent behaviors

This section details the behavior of each type of agents. We used the following notation in the equations. Consumption firms variables have a c subscript, capital firms a k, households a h and banks a b. If the variable is identical for consumption and capital firms, we used the x subscript. All agents share the same simple adaptive scheme to compute expectations (indicated by a e superscript) for a generic variable z:

$$z_t^e = z_{t-1}^e + \lambda (z_{t-1} - z_{t-1}^e)$$
(4.1)

4.1 Firm behavior

4.1.1 Production planning and labor demand

Firm x desired output in period $t(y_{xt}^D)$ depends on the firm's sales expectations s_{xt}^e . We assume firms want to hold a certain amount of real inventories, expressed as a share ν of expected sales, as a buffer against

unexpected demand swings (Steindl, 1952) and to avoid frustrating customers with supply constraints (Lavoie, 1992).

$$y_{xt}^D = s_{xt}^e (1+\nu) - inv_{xt-1} \text{ with } x = \{c, k\}$$
(4.2)

Firms in the capital-good industry produce their output out of labor only. Capital firms' demand for workers depends on y_{kt}^D and the labor productivity μ_N , which we assume to be constant and exogenous.

$$N_{kt}^D = y_{kt}^D / \mu_N \tag{4.3}$$

The labor requirement of any consumption firm c can be calculated as:

$$N_{ct}^{D} = u_{ct}^{D} \frac{k_{ct}}{l_{k}}.$$
(4.4)

where u_{ct}^D is the rate of capacity utilization needed to produce the desired level of output y_{ct}^D :

$$u_{ct}^{D} = Min(1, \frac{y_{ct}^{D}}{k_{ct}\mu_{K}}),, \qquad (4.5)$$

where k_{ct} indicates the real stock of capital. The technology embedded in capital goods is defined by the binary $\{\mu_K, l_k\}$ where the former parameter indicates capital productivity and the latter the constant capital-labor ratio.

We assume a positive employee turnover, expressed as a share ϑ of firm's employees (sec.4.1.6). Firms then determine wether they need to hire new workers or fire some of them. Redundant workers are randomly sampled from the pool of firm employees.

4.1.2 Pricing

Prices of goods are set as a non-negative markup mu_{xt} over expected unit labor costs:

$$p_{xt} = (1 + mu_{xt}) \frac{W_{xt}^e N_{xt}^D}{y_{xt}^D},$$
(4.6)

where W_{xt}^e is the expected average wage.

The mark up is endogenously revised from period to period following a simple adaptive rule. When firms end up having more inventories than desired (see sec.4.1.1), the markup is lowered in the next period, in order to increase the attractiveness of their output.

$$mu_{xt} = \begin{cases} mu_{xt-1}(1+FN) & \text{if } \frac{inv_{xt-1}}{s_{it-1}} \le \nu \\ mu_{xt-1}(1-FN) & \text{if } \frac{inv_{xt-1}}{s_{it-1}} > \nu, \end{cases}$$
(4.7)

where FN is a random number picked from a Folded Normal distribution with parameters $(\mu_{FN}, \sigma_{FN}^2)$.

4.1.3 Firms' profits

Firms' pre-tax profits are the sum of revenues from sales, interest received, and the nominal variation of inventories,⁵ minus wages, interest paid on the collection of outstanding loans, and eventually capital amortization flows.

Formally, for consumption firms:

$$\pi_{ct} = s_{ct} p_{ct} + i^a_{bt-1} D_{ct-1} + (inv_{ct} uc_{ct} - inv_{ct-1} uc_{ct-1}) \dots$$

$$\dots - \sum_{n \in N_{ct}} w_{nt} - \sum_{j=t-\eta}^{t-1} i^j_j L_{cj} \frac{\eta - [(t-1)-j]}{\eta} - \sum_{k \in K_{ct-1}} (k^k p^k) \frac{1}{\kappa}$$
(4.8)

where i_{bt-1}^d is the interest rate on past period deposit D_{ct-1} held at bank b, uc_c are unit costs of production, w_{nt} is the wage paid to worker n, i_i^l is the interest rate on loan L_{cj} obtained in period

 $^{{}^{5}}$ In accordance with standard accounting rules, firms' inventories are evaluated at the firms' current unit cost of production. As a consequence, the value of inventories may vary due to variation of either their quantity or of their productive costs.

 $j = t - \eta, ..., t - 1, p^k$ is the price paid for the batch of capital goods k^k belonging to the firm's collection of capital goods K_{ct-1} , and $\eta = \kappa$ are the duration of loans and capital respectively. Similarly, capital firms' profits are given by:

$$\pi_{kt} = s_{kt} p_{kt} + i_{bt-1}^d D_{kt-1} + (inv_{kt} uc_{kt} - inv_{kt-1} uc_{kt-1}) \dots$$

$$\dots - \sum_{n \in N_{kt}} w_{nt} - \sum_{j=t-\eta}^{t-1} i_j^l L_{kj} \frac{\eta - [(t-1) - j]}{\eta}$$
(4.9)

This accounting definition of profits is then used to compute the amount of taxes firms have to pay: $T_{xt} = Max \{\tau_{\pi}\pi_{xt}, 0\}, \tau_{\pi}$ being the corporate profits tax rate. We also consider an alternative measure of firms' performance in order to capture the actual ability of the firm to generate cash inflows (which can be accumulated or used to finance investment or to distribute dividends) through its normal business operation.⁶ We define the 'operating cash flow' as their income out of sales or interest perceived minus the wage bill and total debt service (i.e. interest and principal payments):

$$OCF_{xt} = s_{xt}p_{xt} + i_{bt-1}^d D_{xt-1} - \sum_{n \in N_{xt}} w_{nt} - \sum_{j=t-\eta}^{t-1} \left(i_j^l L_{xj} \frac{\eta - [(t-1) - j]}{\eta} + \frac{L_{xj}}{\eta} \right)$$
(4.10)

Notice that the operating cash flow can be interpreted as a sort of 'Minskian' litmus paper to assess whether a firm is in a *hedge*, *speculative*, or *Ponzi* financial position. An $OCF \ge 0$ implies that the firm is capable of enough generating cash flow to honor the debt service (hedge position). If the OCF is negative, but its absolute value is less than or equal to the principal repayment, the firm is in a speculative position since its cash flows are sufficient to cover the interest due, but the firm must roll over part or all of its debt. Finally, when the OCF is negative and its absolute value is greater than principal payments, the firm is trapped in a Ponzi position.

4.1.4 Investment

Firms invest in each period in order to attain a desired productive capacity rate of growth g_{ct}^D which depends on two ratios: the desired rate of capacity utilization u_{ct}^D (4.5) and the past period value of a 'modified' rate of profit r_{ct} , based on operating cash flows rather than on accounting profits.

$$g_{ct}^{D} = \gamma_1 \frac{r_{ct-1} - \overline{r}}{\overline{r}} + \gamma_2 \frac{u_{ct}^{D} - \overline{u}}{\overline{u}}$$

$$\tag{4.11}$$

$$r_{ct} = \frac{OCF_{ct}}{\sum_{k \in K_{ct-1}} (k^k p^k)(1 - \frac{age_{kt-1}}{\kappa})}.$$
(4.12)

Here, \overline{u} and \overline{r} denote firms' 'normal' rates of capacity utilization and profit respectively, both assumed to be constant and equal across firms. The denominator in equation (4.12) expresses the previous period value of the firm's stock of capital, with age_{kt-1} indicating the age in period t-1 of the batch of capital goods k belonging to the collection K_{ct} of firm c.

Given g_{ct}^D , we can derive the real demand for capital goods i_{ct}^D as the number of capital units required to replace the obsolete capital⁷, and to fill the gap between current and desired productive capacity level. Once firms have chosen their capital good suppliers, nominal desired investment I_{ct}^D can be computed by multiplying i_{ct}^D for the price p_{kt} applied by the selected supplier k.

4.1.5 Firms' finance

Since Fazzari et al. (1988), more and more empirical evidence contradicting the Modigliani and Miller (1958) theorem which predicts that, at the margin, alternative sources of finance should be perfect substitutes have been gathered. Solid arguments have been provided in favor of a pecking order theory of finance (Meyers, 1984), according to which firms mainly rely on their retain earnings and only resort to external financing when internal funding possibilities have been completely exhausted. In the presence

 $^{^{6}}$ The accounting definition of profits includes accounting items, such as the variation of nominal inventories and capital amortization, which are not matched by any actual cash flow during the period, while it omits others which do give rise to cash flows, such as principal repayments of outstanding loans.

⁷For sake of realism, we assume that the financial value of each capital batch is lowered by a constant share $(1/\kappa)$ of the original purchasing value in each period, while the correspondent real stock of machinery can be used at full potential till it reaches $age = \kappa$

of imperfections in capital markets (e.g. information asymmetries), the cost of external finance (equity emissions and loans) is usually high. Credit demand should then be defined as the difference between expected net disbursement and available internal funds. However, firms almost never arrive to the point of exhausting all their internal resources before asking for credit. We therefore adopt a slightly modified version of the pecking order theory adopted in most macro-AB models, by assuming that firms desire to hold a certain amount of deposits, expressed as a share σ of the expected wages disbursement, for precautionary reasons. The demand for credit by consumption firms is then:

$$L_{ct}^D = I_{ct}^D + Div_{ct}^e + \sigma W_{ct}^e N_{ct}^D - OCF_{ct}^e$$

$$\tag{4.13}$$

where Div_{ct}^e are expected dividends distributed to equity holders (i.e. households). Actual dividends are computed as a constant share ρ_x of firm's expected after-tax profits: $Div_{xt} = Max \{0, \rho_x \pi_{xt}(1 - \tau_{\pi})\}$. The credit demand function for capital firms can be easily derived from equation (4.13) by simply omitting I^D .

4.1.6 Labor, Goods and Deposit markets

After the credit market interaction between banks and firms has taken place, firms interact with unemployed households on the labor market. Production then takes place. Firms' output can be constrained by the scarcity of available workers (i.e. full employment case) or, in the case of consumption firms, by their stock of capital (i.e. capacity constraints). Once the production process has been accomplished households and consumption firms interact on the consumption good market.

The second phase of the market interaction on capital market then takes place with consumption firms buying capital goods previously ordered (see sec.4.1.4).

Finally, gross profits π_{xt} are computed, taxes T_{xt} are paid, and dividends Div_{xt} distributed to house-holds (see sec.4.4).

4.2 Bank behavior

In our model, every time new credit is granted, two accounting items are added to the balance sheets of the bank and the borrowing firm: a loan and a correspondent deposit. Despite the story still described in many economic textbooks, today it is widely recognized (see for example the two authoritative contributions by Benes et al. (2014) and McLeay et al. (2014)) that in the process of making new loans, commercial banks create matching liabilities in the form of bank deposits for their borrowers, thereby expanding their balance sheets. The main implication of the credit creation process is that bank loans give borrowers new purchasing power, that is create new means of payment, that did not previously exist.

Another crucial aspect of the credit creation process, which is often dismissed, is that loans represent a long term commitment both for borrowers and lenders. Banks full flexibility to expand their balance sheet while they are constrained when they want to downsize it as loan contracts contain detailed commitments regarding amortization schedules. Most of the risk lenders' have to bear originates from this temporal dimension of credit. On the other hand, it should be straightforward that banks ability to create money through new loans is limited by the need to remain profitable in a *competitive* banking system.

Long term duration of loans and a financial system composed of multiple competing banks should then be two fundamental features of every model aiming at studying the role of credit in modern macroeconomic systems.

Nonetheless, the vast majority of previous macroeconomic computational models either assume loans to have a one period maturity, or they assume a single giant bank, or that the credit network of firmsbanks is pre-determined once and for all in the simulation set-up.⁸ In our model, we assume loans to last for $\eta = 20$ periods (i.e. 5 years)⁹ and we allow firms to interact with several banks on the credit market during each simulation round.¹⁰ From period to period, firms may switch from one bank to another so that they will generally have a collection of heterogeneous loans with different banks on the liability side of their balance sheets.

⁸We believe that the main reason for these simplifying assumptions is not to be found on the theoretical level, but rather in the technical difficulties to handle the multiplicity of heterogeneous loans characterized by different age, different interest rates, different liability and asset holders, etc. JMAB effectively overcomes these difficulties by exploiting the opportunities of Object Oriented Programming.

⁹Loans are repaid following the same amortization scheme: in each period firms repay a constant share $(1/\eta)$ of the original amount.

 $^{^{10}}$ To our knowledge, the only model sharing these features is the Eurace/Eurace - UniBi model (Raberto et al., 2012; van der Hoog and Dawid, 2015)

On the supply side, banks can grant several loans to different firms within the same period. Our matching mechanism on the credit market therefore implies that lenders and borrowers are linked through a complex bipartite network endogenously evolving through the simulation.

Another crucial aspect of our modeling approach to credit market regards the implementation of the credit rationing mechanism. In the earliest AB macroeconomic literature, banks were assumed to accommodate loan requests by borrowers, eventually discriminating borrowers only through interest rates.¹¹ However, in reality banks mainly discriminate through credit rationing rather than interest rates.

Recently, and clearly in response to the crisis, the AB literature has started to introduce some credit rationing mechanisms. A simple rationing mechanism is presented in Riccetti et al. (2014) which assume banks want to avoid being too exposed towards single borrowers, thereby setting an upper bound to loans that can be grant to single borrowers, expressed as a share of total loans. Dosi et al. (2013) assume a unique bank willing to grant loans up to a given multiple of deposits in each period. When loan requests by firms exceed this maximum level of available credit, those who are badly ranked by banks will be credit constrained. A similar ranking mechanism is also presented in van der Hoog and Dawid (2015), although they have multiple banks willing to accommodates loan requests as long as their overall outstanding credit is compatible with the capital ratio institutional constraint. This feature is also shared by Raberto et al. (2012) where banks accommodates loans as long as the risk-weighted credit demanded by firms is compatible with capital adequacy ratios. Assenza et al. (2015) instead assume there is a maximum admissible loss on each loan, expressed as a share of bank's equity. Given the borrower's estimated probability of default, they define an upper bound to the amount of funds the bank is willing to lend.

In all these credit-rationing mechanisms, the opportunity of a loan tend to be evaluated by relating the riskiness added to the bank's portfolio of assets by the new loan to the bank's current overall financial position. While this somehow reflects the fact that single loan requests must be evaluated also in relation to the banks' overall balance sheet management, we believe that a proper credit-rationing mechanism should also take into consideration the expected internal rate of return associated to each specific credit application.

Most of the computational economics literature presenting explicit credit riskiness evaluation mechanisms still uses only 'stock' indexes to assess borrower reliability. In many cases, the leverage ratio is the unique measure used to compute the probability to default of credit applicants. This, we feel, is not enough do understand the mechanisms truly at play. We do not deny that high debt-to-equity ratios may rise an alarm bell, reflecting a deterioration of borrowers' financial soundness. It must be pointed out however that the leverage ratio, *per se*, does not provide any information about borrowers' actual ability to generate net cash inflows to honor the debt. We therefore present a different procedure to determine credit supply of the banks, based on the following three pillars:

- Active management of banks' balance sheet: in keeping with much of the literature, we assume banks' credit supply must be somehow related to the overall bank financial position. In our model each bank has an endogenously evolving capital ratio target, which for simplicity reasons is assumed to be equal across banks and defined as the average of the sector. Furthermore, we also assume banks' capital ratio has a mandatory lower bound (6%). Banks thus manage their balance sheets in order to pursue their targeted capital ratio through the interest rate strategy, affecting the number of potential customers.
- *Case-by-case credit worthiness evaluation*: banks willingness to satisfy fully, partially, or not at all individual companies' credit demand is based on a comparison between expected cash inflows and expected losses, given the applicant's probability of default and its collateral value.
- *Credit worthiness based on operating cash flows.* Banks' compute borrowers' uni-periodal probability of default, under the hypothesis a loan is granted, by comparing firms' current operating cash flows with the single period payments to serve the debt and repay a share of the principal.

Banks' interest rates on loans depends on the comparison between bank's current capital ratio $CR_{bt} = NW_{bt}/L_{bt}^{Tot}$ and the common target CR_t^T . When the capital ratio is higher than its target, banks are more capitalized than needed and may expand further their balance sheet by granting more loans. Their ability to attract customers is increased by offering a lower interest rate lower than their competitors.

¹¹In the standard framework, loan interest rate were defined as the sum of a bank-specific component, usually related to the bank's financial position (proxied by its net-worth), or an institutionally set base loan rate, and a borrower-specific component (risk premium) increasing with some measures of the borrower's riskiness, typically some net-worth related indexes such as the leverage ratio. See for example Delli Gatti et al. (2010b); Raberto et al. (2012).

In the opposite case, a higher interest rate has the twofold effect of making bank's loans less attractive, while increasing the banks' margin. Formally:

$$i_{bt}^{l} = \begin{cases} \bar{i}_{bt-1}^{l} (1+FN) & \text{if } CR_{bt} < CR_{t}^{T} \\ \bar{i}_{bt-1}^{l} (1-FN) & \text{otherwise} \end{cases}$$
(4.14)

where $\overline{i}_{bt-1}^{l} = \frac{\sum_{b \in \Phi_B} i_{bt-1}^{l}}{size_{\Phi_B}}$ is the market average interest rate in the previous period and FN is a realization of a stochastic variable distributed according to a Folded Normal Distribution (μ_{FN}, σ_{FN}^2).

Case-by-case credit rationing mechanism starts with banks evaluating applicants' single-period probability of default, under the hypothesis thats the loan requested is granted. We define the debt service variable as the first tranche of payment associated to the hypothetic loan: $ds^{L^d} = (i_{bt}^l + \frac{1}{\eta})L^d$. The probability of default is then computed using a logistic function, based on the percentage difference between borrowers' OCF_{xt} and ds^{L^d} :

$$pr_x^D = \frac{1}{1 + \exp(\frac{OCF_{xt} - \varsigma_x ds^{L^d}}{ds^{L^d}})},\tag{4.15}$$

 ς_c and ς_k are two parameters expressing banks' risk aversion in lending to capital and consumption firms. The higher ς the more banks are risk averse (i.e. the higher the probability of default for given *OCF* and ds).

The use of the OCF to assess borrowers' reliability has the advantage, highlighted in section 4.1.3, of providing a clear measure of the borrower financial position if the loan was granted. As the OCF accounts both for interest and principal payments on the existing stock of debt, they allow to capture the effect of high indebtedness just as the leverage ratio, but also providing a criterion to rank potential borrowers' having the same leverage but different performances.

The expected return of a credit project also depends on firms' collateral, when present. Our model assumes that consumption firms can use their stock of real capital as collateral. In the case of default, each bank expects to be able to recover a share δ_x of their outstanding loans to the defaulted firm x through fire sales of its capital.¹² Knowing L^d , i_{bt}^l , pr_x^D , δ_x , we can compute the overall expected return of a credit project by simply summing up the payoffs arising from each possible outcome of the decision to grant the loan, each one weighted for its probability of occurrence. Figure 4.2 provides a graphical representation of the 'payoffs tree'.



 $^{^{12}}$ Notice that, since capital good producers employ only labor in their production process and do not invest in capital accumulation, they have no collateral.

Banks are willing to satisfy agents' demand for credit whenever the expected return is greater or equal than zero. Otherwise, the bank may still be willing to provide some credit, if there exist an amount L^{D*} for which the expected return is non-negative.

Deposits and bonds market

Banks hold deposits of households and firms. Individual banks' amount of deposits depends on two factors: first, firms' and households decisions about where to put their savings; second, agents' autonomous transactions realized through deposit transfers. In this respect, it must be noticed that deposit transfers between different banks also implies a clearing mechanism of transfer of reserves from the paying to the receiving bank.

As banks have to satisfy mandatory liquidity ratios (8%) and since deposits represent a source of reserves much cheaper than Central Bank cash advances (that is, $i_{bt}^d << \overline{i}_{cb}^a$) banks compete with each other on the deposit market.¹³ As in the case of the capital ratio, we assume that banks have, besides the mandatory lower bound, a common liquidity target LR_t^T defined as the sector average in the last period.

In order to attain this target ratio banks manage the interest rate offered on deposits according to a simple heuristic similar to that presented in equation 4.14. When the liquidity ratio is below the target banks set their interest on deposits as stochastic premium over the average interest rate in order to attract customers, and vice-versa when banks have plenty of liquidity.

$$i_{bt}^{d} = \begin{cases} \bar{i}_{bt-1}^{d} (1 - FN) & \text{if } LR_{bt} \ge LR_{t}^{T} \\ \bar{i}_{d}^{d} (1 + FN) & \text{otherwise }, \end{cases}$$
(4.16)

where FN indicates the realization of a stochastic variable drawn from a Folded Normal Distribution $(\mu_{FN}, \sigma_{FN}^2)$.

Finally, we assume that banks use their reserves in excess of their target to buy government bonds.¹⁴ All bonds not purchased by commercial banks are bought by the Central Bank.

4.3 Firms' and banks' bankruptcy

Firms and banks may go bankrupt when they run out of liquidity or if their net-wealth turns negative. For simplicity reasons, we assume defaulted firms and banks to be bailed in by households (who are the owners of firms and banks and receive dividends) and depositors in order to maintain the number of firms and banks constant.

A bankruptcy by a firm induces non-performing loans for its creditors, who see their net wealth shrinking. In the case of capital firms, the loss is totally borne by banks, as capital firms do not have any collateral. In the case of a consumption firm, we assume that its ownership passes temporarily to creditors which try to recover part of their outstanding loans through fire sales of firm's physical capital to households.

In accordance with empirical evidence, we assume the financial value of assets sold through fire sales to be lowered by a share ι , which is assumed to be an exogenous parameter. When the discounted value of capital is greater or equal to the firm's bad debt, the loss caused by the bankruptcy falls completely on households' shoulders while banks are able to recover all their loans.

However, in the general case, the loss is split between households and banks which are able to recover only a fraction of their loans. Individual households contribution to fire sales follows the same rule of dividends distribution (sec.4.4), with the overall disbursement being distributed proportionally to households' net wealth.

The revenues from sales of the firms' assets are then distributed across creditors proportionally to the fraction of firms' total debt they own. It is trivial to show that, given these assumptions, creditors are able to recover the same share $\delta_c < 1$ of their loans, expressed by the ratio between firm's capital

 $^{^{13}}$ Whenever the capital ratio falls below the mandatory threshold banks apply for cash advances to the Central Bank (see 4.5).

 $^{^{14}}$ Remember that, given the sequence of events in each simulation round, government bonds repayment occurs *after* deposit interest rates have been set and deposit market interactions have taken place. This bonds repayments increase banks' reserves providing extra liquidity that banks use to purchase newly issued bonds. In the unlikely case banks are willing to buy more bonds than available, these are distributed across banks proportionally to their demand (i.e. to the employable amount of reserves).

discounted financial value and total bad debt:

$$\delta_c = \frac{\iota \left[\sum_{k \in K_{ct}} (k^k p^k) (1 - \frac{age_{kt}}{\kappa})\right]}{\sum_{j=t-\eta}^t i_j^l L_{cj} \frac{\eta - [(t-1)-j]}{\eta}}.$$
(4.17)

The event of the bankruptcy by a bank, though unlikely, is treated here by assuming that depositors bear the loss associated to the default. In order to restore a positive net-wealth, deposits are lowered up to the point the bank's capital ratio equals the minimum capital adequacy requirement (6%), similar to a bail-in process. The total loss borne by the depositor is distributed proportionally to the scale of their deposits.

4.4 Household behavior

Workers follow an adaptive heuristic to set the wage they ask for: if over the year (i.e., four periods), they have been unemployed for more than two quarters, they lower the asked wage by a stochastic amount. In the opposite case, they increase their asked wage, provided that the aggregate rate of unemployment in the previous period (u_{t-1}) is sufficiently low. This latter condition is meant to mimic the endogenous evolution of workers' bargaining power in relation to employment dynamics.

$$w_i^{d,t} = \begin{cases} w_{ht-1}^D (1-FN) & \text{if } \sum_{n=1}^4 u_{ht-n} > 2\\ w_{ht-1}^D (1+FN) & \text{if } \sum_{n=1}^4 u_{ht-n} \le 2 \text{ and } u_{t-1} \le v, \end{cases}$$
(4.18)

where $u_{ht} = 1$ if h is unemployed in t, and 0 otherwise.

Workers decide how much to consume with fixed propensities α_1, α_2 out of expected real disposable income and expected real wealth. As workers set their real demand before interacting with consumption firms, they construct expectation on consumption good prices p_{ht}^e :

$$c_{ht}^{D} = \alpha_1 \frac{NI_{ht}}{p_{ht}^{e}} + \alpha_2 \frac{NW_{ht}}{p_{ht}^{e}}$$
(4.19)

Gross nominal income is given by $w_{ht} + i_{bt-1}^d D_{ht-1} + Div_{ht}$ if the worker is employed. Households pay taxes on income with a flat tax rate τ_i . Unemployed workers receive a tax-exempt dole from the government defined as a share ω of average wages.

4.5 Government and central bank behavior

The government hires a constant share of households. Public servants are also subject to a turnover ϑ . Furthermore the government pays unemployment benefits (d_t) to unemployed people (U_t) , acting in a counter-cyclical way.

The state collects taxes on income and profits (with constant rates τ_i and τ_{π}) from households, firms and banks and issues bonds b_t (at fixed price \overline{p}^b and interest \overline{i}^b) to cover the eventual deficit between expenses and revenues. Bonds are assumed to last 1 period for simplicity reasons:

$$\bar{p}^{b}\Delta b_{t} = T_{t} + \pi_{CBt} - \sum_{n \in N_{gt}} w_{n} - U_{t}d_{t} - \bar{i}^{b}\bar{p}^{b}b_{t-1}, \qquad (4.20)$$

where $T_t = T_{Ht} + T_{Ct} + T_{Kt} + T_{Ht}$ are total taxes, π_{CBt} are Central Bank profits, N_{gt} is the collection of public workers.

Bonds not purchased by commercial banks are bought by the Central Bank. Notice that Central Bank purchases of government bonds are one of the two channel by which reserves are injected into banks' balance sheets, the other one being represented by cash advances which the Central Bank grants on request by commercial banks. Cash advances are assumed to be repaid after one period and their constant interest rate represents the upper bound for interest paid by banks on customers' deposits. For simplicity reasons, we assume the Central Bank pay no interest on banks' reserves account. Finally, Central Bank earns a profit equal to the flow of interest on its holdings of government bonds and cash advances:

$$\pi_{CBt} = \bar{i}^b B_{t-1} + \bar{i}^a_{CB} C A_{cbt}.$$
(4.21)

As mentioned above, Central Bank's profits are distributed to the government.

5 Baseline setup: challenges in calibration

Calibration represents a crucial issue for every computational model, in particular whenever they entail stochastic, path-dependent, non-ergodic dynamics. Monte Carlo and sensitivity analysis techniques are an essential element in order to assess across-runs variability, to perform robustness checks and policy analysis, and to validate simulation models. This is particularly true for theoretical micro-founded models for which micro-data are often lacking, or non-observable at all.

Before describing our approach to setup the model baseline, we highlight three main challenges related to the calibration process: (i) setting a clear and replicable procedure trying to minimize the arbitrariness in defining parameters values. (ii) making sure that the economy as a whole starts from stock-flow consistent initial conditions iii) define a strategy to characterize and distribute agent-specific stocks starting from aggregate ones.

Technical difficulties, time, and computational limits often prevent the modeller from exploring the entire parameter space, in particular for large-complex macroeconomic model. These models are thus usually analyzed in the local neighborhood of a baseline scenario. Setting up an adequate baseline implies the need to find a strategy to constrain the parameter space, to limit the number of free parameters, and to distribute initial endowments across agents in a way such that initial conditions do not entail any a-priori bias for the phenomena we want to analyze through the simulation experiments. Still, only a few articles presenting computational macroeconomic models provide an exhaustive explanation of the logic followed to calibrate their baseline.

As highlighted in the previous sections, one of the main aspects of novelty of the present work is the implementation of stock flow consistent accounting rules in the bottom-up perspective of agent based models. It is thus important to start from initial conditions respecting a stock-flow consistent distribution of aggregate real and financial stocks across sectors. That is, we shall find a procedure to determine jointly the initial values of different types of stocks held by each sector, respecting Copeland's quadruple entry principle.

Aggregates stocks should then be distributed across agents within each specific sector of the economy, thus specifying the overall shape of agents' initial balance sheets. As described in the previous sections, agents balance sheets are sometimes characterized by the presence of multiple stocks of the same types, which differs in terms of quantity, age, maturity, prices, and liability & asset counterparts. In our model, this is the case for loans in firms' and banks balance sheets, and capital goods in consumption firms' balance sheets (see sec.4.2 and 4.1.4). The third challenge thus consists thus in finding a coherent strategy to characterize each stock in these collections and assign them to each individual agent who hold them as an asset or a liability.

In order to respond to the three challenges, we adopted the following six-step strategy:

- 1. We derive an aggregate version of the model.
- 2. We constrain the aggregate model¹⁵ to be in a real stationary state associated with a nominal steady growth equal to g_{ss} . This imply that while all real quantities are constant, all prices and wages are growing at the same rate g_{ss} .¹⁶
- 3. We numerically solve the constrained model by setting exogenously reasonable values for the parameters for which some empirical information is available¹⁷ (e.g. unemployment rate, mark-ups, interest rates, income and profit tax rates, etc.) or that we want to control (e.g. technological coefficients, number of agents in each sector, distribution of workers across sectors, loans and capital durations). We thereby obtain initial values for each stock and flow variable of the aggregate steady state, as well as for some behavioral parameters coherent with the steady/stationary state (e.g. propensity to consume out of income, target capacity utilization and profit rates, initial capital and liquidity ratio targets for banks).
- 4. We distribute each sector's aggregate values uniformly across agents' in that sector. In this way we derive the total value of each type of stock held by agents (e.g. households' and firms' deposits, total outstanding loans and real capital for each firm, total loans, reserves and bonds for individual banks etc.) and agents' past values to be used for expectations (e.g. past sales, past wages, past profits, etc.).

 $^{^{15}}$ For space reasons, we do not present here the exact system of equation representing the steady state. It can be obtained from the authors, upon request.

 $^{^{16}}$ Notice that the real steady state constraint is due to the fact that the number of households and the technological coefficients are fixed once and for all.

¹⁷Note that these parameters are set having in mind that every period in the simulation represents a quarter.

- 5. We assume that, in each of the periods before the simulation starts, firms have obtained a loan and consumption firms have also invested in new capital to maintain their productive capacity constant. We further assume that the real value (i.e. corrected for inflation) of the new loan or of the new capital goods was constant in each of these periods. Knowing the constant inflation rate g_{ss} and the amortization schedules for capital goods and loans, we can then derive the outstanding value for each of these stocks, so that their total value sums up to the amount determined in the previous step.¹⁸
- 6. In order to set the network structure, we randomly assign a previous period supplier (required for the matching mechanism) to each demand agent on each market, ensuring that each supplier has the same number of customers. Similarly, we assign to each single financial stock in households' and firms' balance sheets, the asset or liability counterpart by randomly selecting a bank. Again, we impose that each bank has the same number (and amount) of deposits and loans with the same number of agents.

The procedure just explained generates an important symmetry condition on agents' initial characteristics: that is, we start from a situation of perfect homogeneity between agents in order to limit as much as possible any possible bias embedded in asymmetric initial conditions, and we let heterogeneity to emerge from the simulation as consequence of cumulative effects triggered by the stochastic factors embedded in agents' adaptive rules. Furthermore, by setting initial values based on SS stock-flow norms we aim to achieve the threefold objective of limiting our arbitrariness in defining agents' initial endowments, restricting the number of free behavioral parameters in the simulation, and find a consistent criterion to set the values of several others.

Table 1 in the appendix shows the exact value of the parameters used in the baseline setup, specifying for each one of them, whether it was exogenously set to determine the steady state ('pre-SS'), derived from it ('SS-given') or following a logic independent from it ('free'). Here is a non exhaustive list of the logic followed to set the values of some important parameters.

- The number of workers initially employed by consumption and capital firms, was set to reflect the relative numerosity of these two classes, so that every firm, regardless the type, starts with the same number of workers.
- The parameters affecting the probability of switching to a new supplier (sec.3.1, were set so that a 15% and 20% difference between the prices of the old and new suppliers gives a probability of 50% to switch.
- Initial mark ups on unit labor costs by consumption and capital firms were set so that the initial markup on total unit costs is 10 % for consumption and 7.5% for capital firms. The parameters of the Folded Normal Distribution used in the prices, wages, and interest adaptive strategies were set so that the expected value of a sample is 0.0075.
- The targets used in the growth functions of firms (capacity utilization and return rates) or in the interest rates setting function of banks (liquidity and capital ratios) were set to their value at the steady state. Similarly, the macroeconomic threshold used by households to decide whether to increase or not their asked wage is set equal to the steady state unemployment rate (8%).
- Banks risk aversion parameters were computed in order to have a single-period probability of default 1%, given the steady state levels of operating cash flow and debt service costs.¹⁹

$$L_{j}^{*} = L_{j-1}^{*} \cdot (1+g_{ss}) \quad \& \quad L_{j} = L_{j}^{*} \frac{\eta - j}{\eta} \quad \& \quad L_{x0}^{Tot} = \sum_{i=0}^{\eta-1} L_{j}$$

Where L_{x0}^{Tot} is the total debt level of the firm and where η is the constant maturity of the loans.

Furthermore, in period 0 each firm will have a collection of κ batches indexed by $i = 0, ..., \kappa - 1$, each one characterized by the same number of machineries $k = k_{x0}^{Tot}/\kappa$ and having an accounting value K_j :

$$K_{j} = \frac{p_{k0}}{(1+g_{ss})^{j}} k \frac{\kappa - j}{\kappa},$$
(5.1)

where p_{k0} is the price of capital good in the steady state.

 19 Note that this value represents the borrower's probability of default estimated by banks for each period from when the loan is granted to its complete repayment. The estimated overall probability of having a default before the loan is repaid is higher.

¹⁸Formally, every firm will have a collection of loans where loan indexed by $j = 0, ..., \eta - 1$ was granted j periods before for an original amount L_j^* and, taking into account loan amortization, has a current value L_j determined as follows:

• The ratio between banks net worth and banks total assets is set equal to 8%.

6 Results

After having calibrated the model through the procedure explained in the previous section, we analyzed the baseline setup by running 100 Monte Carlo simulations for 400 periods. Then, we attempt to validate the model output by comparing the properties of our artificial time series with their real world counterparts.²⁰ We then describe the dynamics observed in the transition phase of the model and the long term properties of the economy. We then ran various parameter sweep scenarios, replicating each scenario 5 times. We focus on the parameters affecting (i) consumption firms' investment decisions, (ii) banks' risk aversion, and thereby firms' access to credit, and (iii) the determinants of firms' demand for credit. After having checked the robustness of our artificial time series fundamental properties across these scenarios, we finally comment on the impact of these parameters on the model dynamics.

6.1 Validation

In order to validate the model, it is worth comparing, from a qualitative and quantitative point of view, the properties of artificial and real world times series²¹ (Assenza et al., 2015). Since our model is calibrated such that one period corresponds to a quarter, 400 periods correspond to 100 years. Trends and cycle components have been separated using the Hodrick-Prescott filter.

Figure 2 presents the cyclical component of the logged artificial time series for GDP, unemployment, investment, and consumption.²² The properties of artificial time series are comparable to observed ones. The figure shows that investment and unemployment volatility are significantly higher than real GDP volatility, while consumption is slightly less volatile than output.

In figure 3, we show the artificial and observed auto-correlations of the de-trended series up to the 20^{th} lag. The auto-correlation structure of artificial times series looks remarkably similar to the auto-correlation function of observed real data. All variables have strong positive first order auto-correlations.²³

Figure 4 shows the cross-correlations between the cyclical component of real output at time t and of real output, unemployment, real investment, and real consumption at time t - lag. The position of the peak in each correlation figure indicates whether the variable is lagged, coincident or leading with respect to output. The shape, dimension and the position of the peak of our simulated time series provide a very good fit of the properties shown by real time series. Investment and consumption are pro-cyclical and coincident variables, while unemployment is counter-cyclical and lagged by a quarter.

In appendix **B** we show how the above highlighted properties of our simulated time series are robust across the experiments performed in the sensitivity analysis. This suggests the correlation structure observed in artificial data is an inherent property of the model rather than being dependent on a specific parametrization. That is, changing the parameters of the model, changes the behavior of agents (thereby obviously affecting systemic dynamics), but not the underlying correlation structure of macroeconomic variables. The model thus seems to be able to grasp the structural interdependencies between macro variables observed in real world.

The model is also able to reproduce several other important stylized facts. Despite agents within each class being almost perfectly homogeneous at the beginning of our simulations, heterogeneity emerges during the simulation, first as a consequence of the inherent stochasticity affecting agents' interactions and adaptive behaviors, and then as the result of the path-dependent/cumulative effects arising from agents' competition on real and financial markets.

 $^{^{20}}$ The term validation must be carefully interpreted. Here we generally refer, as usual in the AB macroeconomic literature, to the model ability to generate micro and macro stylized facts observed in reality. Nonetheless, we are aware of the fact that this, *per se*, is not a sufficient condition to accept a theory, or model. The principles of empiricism, dating back to David Hume, imply the impossibility to validate in any conclusive way any general scientific law, valid in all places and at all times. This is even more true for Political Economy, given its status of social science. For a detailed discussion on the epistemological framework of economic theory, see Focardi (2015).

²¹Real time series are taken from the Federal Reserve Economic Data (FRED): they are quarterly data ranging from 1955-01-01 to 2013-10-01 for unemployment (not seasonally adjusted, FRED code: LRUN64TTUSQ156N) and ranging from 1947-01-01 to 2013-10-01 for investments, consumption and GDP (FRED codes: PCECC96, GPDIC96, and GDPC1 respectively).

²²Note the change in scale for the Unemployment graph.

 $^{^{23}}$ A remarkable difference, however, has to be found in the 20^{th} auto-correlation of investment and unemployment which look significantly higher than real ones. This inconsistency is easily explained in light of our assumption that real capital has a duration of 20 periods before being scrapped off. This introduces a significant cyclical component in real investment.



Figure 2: Cyclical components of logged simulated times series for Output, Unemployment, Investment, and Consumption



Figure 3: Average artificial (continuous) and real (dashed) auto-correlations of the de-trended series up to the 20th lag. Bars are standard deviations of Monte Carlo average auto-correlations.

In this respect, the selection processes taking place in all markets affects the evolution of their structures. This can be observed in a general tendency towards increasing market concentration. This appears evident when we look at firms' size distribution and banks' outstanding credit distribution. Figure 5 high-



Figure 4: Average artificial (continuous) and real (dashed) cross-correlations of the de-trended series up to the 10th lag. Bars are standard deviations of Monte Carlo average cross-correlations.

lights that firms and banks are highly heterogeneous with respect to their size distribution. Furthermore, both the distribution of firms' sizes and the distribution of banks' credit degree appear to be right skewed, with upper tails represented by few large firms and banks, having respectively greater dimension and higher outstanding credit than predicted by a normal distribution.



Figure 5: Panel a: Banks' credit degree distribution. Panel b: Firms' Dimension

Finally, although our assumptions do not allow for long-lasting real growth, because the number of workers and the productivity levels are constant and exogenously pre-determined, the model is able to produce exponential long-term nominal growth and moderate inflation. In the baseline quasi steady-state, prices of consumption goods and nominal GDP grow at an annual rate of approximately 1.6-1.8% (see figure 6).

6.2 The transition

The process used for the calibration of our model, as described in the previous section, has to be taken with a grain of salt. Despite our attempt to constrain our arbitrariness in setting initial conditions, we are aware that the choice of using the logical construct of a specific aggregate steady state with homogeneous agents and symmetric conditions entails a certain degree of discretionality as well.

Nevertheless, starting from initial conditions derived in such a way does not imply either the model dynamics stick to the original steady state, nor does it imply the symmetry condition continues to hold throughout the simulation. Whereas in computing the initial steady state the rate of growth of nominal variables was fixed exogenously, these constraints are removed as soon as the simulation begins and agents start to react through their stochastic adaptive rules. As heterogeneity emerges out of the interactions of the agents composing the model, the "inherent" dynamics of the model starts appearing.

While in the previous section we focused on the properties of the cycle component of our artificial time series, this section aims at analyzing the trended dynamics and properties of the model in the baseline configuration. Therefore, we now use the HP filtered time series focusing on the trend component rather than on the cyclical one. Results presented in this section are obtained by averaging the trends across the 100 Monte Carlo simulations ran with the baseline parameter set.

Several forces concur in shaping the dynamics observed in artificial time series. First of all agents interact in a decentralized way on the different markets. Since the economy lacks of any coordinating mechanism supervising agents' and sectors exchanges, thereby ensuring a balanced growth of inflows and outflows across sectors, agents' autonomous interactions may and generally do lead to significant changes in the sectoral distribution of real and financial stocks. This in turn, may affect the stability of aggregates stock-flow norms. When some sectors accumulate increasing liquid resources at the expense of another, who experiences a drain, we might go into a crisis.

Tracking the evolution of inter-sectoral flows and their impact on sectors' balance sheet is thus crucial to understand the mechanics of the economic system at hand. However, looking at aggregate sectoral variables is not sufficient to achieve a deep understanding of the model underlying dynamics. A second type of interaction across agents play a crucial role. This is the interaction between agents within the same class, which takes the form of the competitive processes undergoing on the different markets.

Therefore, while the analysis of inter-sectoral flows can help identifying aggregate imbalances, the analysis of the micro evolution of agents' balance sheet and market structures may help to identify imbalances within a sector. For example, it might be the case that while profit margins for consumption or capital good producers tend to decrease or increase in the aggregate, some firms are recording increasing profits, while others are experiencing a dramatic deterioration of their financial position, which may result in a bankruptcy, thereby introducing strong non-linearities in the model.

Interestingly, our artificial time series show the model first experiences a succession of expansionary and recession trends, then converging, in most cases, to a relatively stable configuration of the economy in which main real aggregates fluctuate around stable values, and nominal aggregates grow at similar rates, fluctuating around a steady level. We refer to this situation as a "stochastic steady-state", or "quasi steady-state" (quasi-SS), while the previous time span constitutes the transition phase of the economy.

Our sensitivity experiments show that the properties of this quasi-SS, such as the level of unemployment, consumption, investment, and inflation, or the presence of cyclicality in trends, depend on the configuration of agents' behavior.

These experiments also show that the convergence to a specific quasi-SS depends on the path experienced by the economy during the transition phase. That is, the long run properties of the economy are different according to whether agents' disperse interactions and adaptive behaviors generate strong intersectoral imbalances over the transition phase or, instead, favor a smooth convergence of stock-flow norms towards steady, or slightly fluctuating, levels. For this reason we believe it is interesting to understand the dynamics at stake during the transition phase, before characterizing the quasi-SS of the model.

The transition phase can be divided into three broad phases. Figure 6 presents a dashboard of various important variables time series.²⁴

Phase 1 - Self-sustained Growth Our simulations starts from a situation of perfect symmetry between agents within the consumption firms, capital firms, households, and banks sectors. The first periods of each simulation are thus heavily affected by this particular set-up, showing a rapid increase in unemployment, followed by an equally rapid recovery.²⁵

 $^{^{24}}$ Growth rates of prices for each simulation have been computed using the average of prices offered by individual firms in each period, each one weighted for the firm's market share.

²⁵More precisely, at initial conditions, all firms revise the prices of their output in the same direction, leading to a generalized increase of consumption and capital goods prices. On the contrary, only employed workers revise their asked wages upwardly, so that average net income do not keep the pace with consumption prices. Households' loss of purchasing power results in a fall of real consumption, and a consequent shrink of employment. However, increased profit margins stimulate investment. In the meanwhile, as the stochastic variation in firms' prices becomes high enough to induce some



Figure 6: Continuous lines are mean trends over Monte Carlo Simulations. Dashed lines are trends standard deviations across Monte Carlo runs.

The time between periods 10 and 45 displays a self-fuelling and sustained real growth process, mainly driven by real consumption: higher demand leads to higher employment which, in turn causes further increases in demand, both directly, and indirectly, through the wages inflationary process undergoing in a context of low unemployment. Figure 6 shows that during this phase households net-income rises steadily at a higher (and increasingly) pace than inflation. Demand for consumption goods keeps rising. On the contrary, real investment in this phase is stable at original values as a consequence of a compensation mechanism between higher capacity utilization rates, positively affecting consumption firms' desired growth, and lower profit rates. Consumption firms' profits rates in fact are squeezed by the reduction of realized markups arising from price and wage dynamics,²⁶ which lowers the numerator, and by the increased prices of capital goods, augmenting the denominator.

The reduction of profit margins exerts another effect which is crucial in driving the dynamic of the system, that of reducing the amount of internal funding available to finance production and investment, relative to the overall financial requirement of firms. The rise of wages and employment increases the amount of precautionary deposits firms' want to hold. This depicts a situation in which, on average, consumption firms are more reliant on external finance. Credit may help firms to face temporary swings in their revenues, making up possible short-term shortages of liquid resources. More credit, however, also means greater amounts of liquid resources being diverted towards debt service. Whether credit acts as a stabilizing or destabilizing factor primarily depends on which of the two former effects prevails in a given time span.Figure 6 shows that this tendency is somehow tempered by a tightening of banks credit rationing behavior, as a consequence of falling operating cash flows.

However, the situation at the micro level is far more variegated. Some firms outperform and experience increasing profits while some are undergoing a dramatic drain of liquid resources.

Phase 2 - Trend inversion and great recession Wage growth rates tend to stabilize around period 40. Expectations bias on wages seems to fade out, and inflation catches up and surpasses nominal wage growth, compressing household purchasing power. In the meantime (around period 35) some firms default, not being able to pay wages and honor their outstanding debt. Firm defaults exerts three effects on the economic system. First, wages not paid to workers reduce current demand for consumption goods. Second, fire sales of defaulted firms' capital goods reduce household deposits (via the process described in section 4.3). Finally, firms' default may result in bad-debt affecting banks' balance sheets and capitalization, with non-trivial effects on firms' behavior depending on the dimension of non performing loans, individual banks' exposure, and the number of banks involved.

These processes contribute to an inversion of the expansionary trend and trigger a vicious spiral augmented by the negative feedbacks between successive slumps in demand and peaks of unemployment. As a consequence, wages fall and inflation slows down, although the lag characterizing prices dynamics induces a further loss in household purchasing power. Between period 45 and 130 unemployment rises fairly steadily, mirroring the progressive fall of real consumption.

Again, the situation at the microeconomic level is more differentiated. Only some of the firms are able to react to the adverse economic environment and continue to grow, while an increasing number experiences a deep crisis so that the number of defaults keeps rising. The great recession undergone by the economy thus affects also the evolution of markets structure, fostering a process of increasing concentration on real markets.

Phase 3 - Recovery and convergence to the quasi steady-state Around period 130, the dynamics of the model, which during the previous stages was mainly driven by real consumption, starts to be more and more dependent on investment. The positive spread between the fall in wages and that in prices, while reducing households purchasing power, tends to increase consumption firms' profit margins. Similarly, the fall of capital prices reduces firms' investment-related outlays and exert a positive impact on the profit rate (by decreasing the denominator). Finally, defaulted firms are allowed to restart without the burden of their previous debt, fostering a deleveraging process of the economy. All these aspects concur to generate a spur of investment, notwithstanding the fall of average capacity utilization rates.

customers to switch towards new suppliers, some firms start reducing their markups in order to recover sales. This dampen inflation, stimulating a recovery of real wages. The cycle is then reverted.

²⁶Note that prices and net-income growth rates follow very similar trends, though trends in prices follow the dynamics of net-income with a lag. This lag is particularly pronounced in the case of consumption prices and can be explained by the fact that consumption prices are set as an adaptive mark-up over expected unit labor costs. This implies that whenever wages increase or decrease at increasing pace, simple adaptive expectations systematically underestimate or overestimate their levels, so that realized mark-ups are systematically lower or higher than desired ones. For expectations to catch up with actual values, it is required that rates of growth stabilize.

Large firms', who are characterized by high rates of capacity utilization despite the general recession, play a crucial role in fostering the recovery of the economy. While real investment is increasing, real consumption hits the ground around period 130 and then stabilizes. The system progressively converges to the quasi steady-state position with unemployment fluctuating just below 8%. After some period, real investment also stabilizes around the level just sufficient to replace obsolete capital, so that cosumption firms' overall capacity stop growing. It is interesting to notice that the level of real consumption and real investment in the new steady state are respectively lower and higher than in the intiial situation while unemloyment is almost the same, implying a redistribution of employees between consumption and capital firms. In the quasi steady-state neither the aggregate profit rate nor the capacity utilization rate are at their target levels. Instead, the former is higher while the latter is lower, compensating each other in the determination of investment.

6.3 Sensitivity analysis

The above discussion highlights the prominence of agents' behaviors in shaping the long-term dynamics of the model. Our previous analysis shows that investment and credit demand behaviors by firms on the one side, and credit supply behaviors by banks on the other, play a crucial role in steering the economy across successive expansionary and recessive phases.

Obviously, many other behavioral assumptions may exert an impact on the model dynamics. For example, different thresholds in workers asked wage function, or different turnover ratios by firms may turn out to be less favorable to workers, affecting the dynamics of wages and profits. Similarly, tax rates and other policy parameters characterizing government behavior are likely to exert a huge impact on the model. Parameters characterizing agents interactions through the common decentralized matching mechanism may also exert an impact on the process of competition between agents, and consequently on the evolution of industries and the dynamics of aggregate variables.

Space constraints and explanatory clarity reasons prevent us to perform a sensitivity analysis on all these parameters. Given their significance in understanding the model dynamics, we chose to focus on those parameters referring to investment and credit behaviors. We perform 5 sensitivity analysis on the following parameters: ς_c and ς_k , defining banks' risk aversions in assessing consumption and capital firms reliability, γ_1 and γ_2 , defining respectively the weights given to the profit rate and capacity utilization arguments in consumption firms' desired growth function, and σ expressing firms' precautionary deposits as a share of firm's expense for wages. Each sensitivity analysis is carried out by performing a parameter sweep over the parameter of interest. The range of variation for each parameter is specified in table 1, in the appendix. For each parameter configuration (i.e. for each scenario) we ran 5 Monte Carlo simulations. Figures 7 and 8 show the averages of the variables trends over the Monte-Carlo simulations for each sensitivity experiment (each row referring to a specific sensitivity analysis).

6.3.1 Differential risk aversion among banks

In our first sensitivity experiments, we analyze the effects of different risk attitudes by banks in evaluating borrowers' probability of default represented by the parameters ς_k or ς_c in equation (4.15).

The first case, namely the risk aversion of banks when assessing capital firms' probability of default, does not show any significant variation with respect to the baseline scenario. Trends in real consumption, real investment, unemployment and inflation are overlapping across the different scenarios, suggesting that capital firms' indebtedness plays a minor role in the dynamic of the model.

On the contrary, the first row of figures 7 and 8 show that different degrees of accessibility to credit by consumption firms exert important and not-trivial effects on the real and nominal dynamics of the model, both in the medium and long run. High values of banks' risk aversion tend to be associated with:

- higher real consumption and moderately lower real investment in the long run;
- moderately lower unemployment levels in the quasi steady-state;
- more volatility in real trends fluctuations in the quasi steady-state;
- higher inflation and indebtedness of consumption firms.

The latter result is somewhat surprising, as we would expect more stringent credit constraints by banks to dampen credit and inflation growth. This apparent paradox can be explained by looking at the dynamics of the transition phase towards the quasi steady-state: a more prudent attitude by banks prevents consumption firms to go into too much debt in the first expansionary phase, as well as in the



Banks risk aversion towards consumption firms

Figure 7: Consumption, Investment, and Unemployment. Lighter gray lines correspond to higher values of the parameter.

Banks risk aversion towards consumption firms



Consumption firms growth function: capacity utilization weight





12.0

11.5

11.0



200

300

400



Figure 8: Logs of GDP and aggregate outstanding²⁶debt of consumption firms. Lighter gray lines correspond to higher values of the parameter.

periods of the ensuing recession, lessening in a significant way the amplitude and duration of the recession. In the two experiments in which the risk aversion parameter is the highest, the economic system is able to avoid the crisis and shows a smooth transition towards the quasi steady-state. The prevention of the recession in turn enables the system to attain a balanced growth of prices, wages, profits, investment, GDP, and credit, avoiding the emergence of excessive imbalances in financial flows between different sectors. The economy ends up having more credit and more inflation than in the baseline, in spite of the fact that firms are individually subjected to stricter credit constraints.

6.3.2 Investment behavior

The next parameter sweep consider the case of the weights (γ_1, γ_2) of the consumption firms' desired growth function (4.11). We start with γ_2 , the weight given the the rate of capacity utilization. The second line of figures 7 and 8 highlight that the higher γ_2 :

- the higher real consumption tends to be in the long-run;
- the lower investment in the quasi steady-state;
- the lower the unemployment rate;
- the greater the amplitude of real trends fluctuations in the quasi steady-state.²⁷

The effect on nominal variables, however, are far less trivial. For example, consumption firms' indebtedness is significantly higher in the extreme cases (very low or very high value of γ_2). A similar non-monotonic relationship seem to hold also between γ_2 and GDP. In fact, nominal output is the highest in the two extreme cases, although the contribution of investment and consumption to GDP differs between the two cases: nominal investment and nominal consumption are respectively higher and lower, reflecting the dynamics of their real equivalents discussed above.

In order to understand this non-trivial dynamics we have to look again at the whole path of the economy, from the beginning to the convergence towards the quasi steady-state. In the extreme experiments, the economy avoids major downturns and this allows a smoother transition phase, which in turn foster nominal growth, as already explained in the previous section. However, the 'mechanics' by which this happens is quite different in each of the extreme cases.

In the 0-weight case, investments recover faster during the recession (phase 2 in the transition): real investment rises faster because of the increasing profit margins arising from capital prices and wage stagnation (see section 6.2), notwithstanding low demand and capacity utilization rates. The higher investment in turn compensates for the fall in consumption, lessening the amplitude and duration of the recession and avoiding major unemployment outbreaks.

On the contrary, in the high-value cases, the investment function dissuade firms to invest too much when unemployment starts to rise (between phase 1 and phase 2 in transition). This in turn reduces consumption firms' financial requirement, preventing firms from undergoing excess credit. Lower indebtedness implies lower debt service, which increases dividends and reduces the number of defaults relative to the baseline, fostering again a smoother transition towards the quasi steady-state.

This sensitivity analysis highlights how two opposite mechanisms arising from very different behaviors by firms may lead to a similar stable configuration of the system.

The second sensitivity experiment considers the case of firms paying more or less attention to their profitability in deciding investment (γ_1). In the zero-weight case, the economy always collapses suggesting that whenever firms invest based only at their current demand (reflected in the capacity utilization rates), while disregarding their current profitability, they tend to invest beyond their possibility and default. A value of 0.005 instead shows a general collapse in 1 out of 5 simulations.

The third row of figures 7 and 8 show the results of our experiments in the non-collapsing cases. We observe that, as γ_1 increases:

- real consumption and real investment in the quasi steady-state tend to be moderately lower and higher;
- unemployment tends to be slightly lower;
- nominal GDP and consumption firms' aggregate outstanding debt tend to be lower at the beginning but higher in the long-run.

 $^{^{27}}$ This can be easily explained in light of the fact that increasing the weight of capacity utilization in the desired growth function increases the procyclicality of investment.

The effects of increasing the weight attributed to the profit rate argument in the desired growth function of consumption firms, are then somehow similar to the results obtained by increasing the banks' risk aversion and firms' capacity weight parameters. Also in this case highest values of γ_1 prevent a major crisis, lessening the duration and extent of the recession. However, the mechanics, though similar, operates with different timing, exerting its effects mainly during the first expansionary phase (phase 1 in the baseline description) rather than in the slowdown and recession phases (phase 2 in the baseline description): here lower profit margins in the initial phase, arising from the faster increase in wages and capital prices relatively to consumption prices (see section 6.2), limits firms' frenzy in the expansionary phase preventing them to undergo excessive investment and credit and favoring a smoother transition towards the quasi steady-state.

6.3.3 Credit Demand

In our final sensitivity experiment, we perform a parameter sweep on the share of expected wage disbursement that firms want to hold as precautionary deposits (σ). This allows us to investigate the impact of different credit demand behaviors: the higher σ , the higher firms' credit demand, all other thing being equal.²⁸ Results of experiments (last row of figures 7 and 8) show that: .

- the higher the share of precautionary deposits firms want to hold, the more the system is unstable and the broader real trends fluctuations tend to be.
- Unemployment is significantly lower for the lowest 4 values. Real consumption and real investment are respectively higher and lower for lower values of σ ;
- long-run nominal GDP and consumption firms' indebtedness tends to be higher when firms want to hold less deposits for precautionary reasons.

•

Similarly to the banks' risk aversion sensitivity analysis, these experiments also give rise to some counter-intuitive results, as we would expect firms indebtedness and prices inflation to increase the more firms are prone to borrow. This again can be explained by analyzing the entire path of evolution of the economy throughout the simulation. Lower values of σ implies a more conservative behavior of firms towards credit, lowering debt service and increasing dividends. The consequent smoother transition towards the quasi steady-state produces similar results to other cases in which major downturns are avoided. Finally, it is interesting to notice that, while the model is very sensitive to variations of σ between 0.5 and 0.9, further progressive increases (0.9 to 1.5) do not change significantly the the long term properties of the system.

7 Conclusions

The paper started from a discussion of the potentialities, advantages, and current limits faced by two innovative modeling approaches to macroeconomics, namely the Agent Based and the Stock Flow Consistent approaches. In that context, we argued in favor of a combination of the two methodologies to be built on an explicit and realistic modeling of individual agents balance sheets and a consistent representation of their co-evolution driven by agents' disperse exchanges. The present work aims at responding to this call by providing a relatively simple, general and flexible benchmark macroeconomic AB-SFC model, as well as a set of coherent rules to calibrate, analyze, and validate it.

Our preliminary results show that the model is able to generate persistent economic fluctuations and to replicate several important micro and macro stylized facts observed in real economies. The model provides a good approximation of real world aggregate variables auto and cross correlation structures, which appears to be robust under different parameterizations, supporting the model candidature to serve as benchmark.

The analysis of the long term dynamics highlights that, under the majority of cases analyzed, the economy tends to converge to what we defined as a "quasi-SS", thus providing a starting point and a benchmark to perform policy and scenario analysis in the next works.

²⁸Before analyzing results it must be stressed that, unlike previous sensitivity analysis in which experiments were conducted on free parameters, parameter σ is deeply related to the setup of agents' initial endowments, as its value was pre-determined in order to derive the aggregate initial steady state employed to calibrate the model initial conditions. However, for reasons of comparability between different experiments, we continue to employ the baseline initial setup and change the values of σ .

In the present work we focused our attention on the analysis of the impact of different investment and credit behaviors by agents on the transition and the long-term properties of the system, which we carried out by performing sensitivity analysis on a subset of parameters shaping firms' and banks' attitudes in investing and financing.

Results suggest that the interaction of real and financial factors plays a crucial role in driving both short-term business cycles and the long-term evolution of the economic system. Under certain conditions firms and banks may be involved in excessive investment and credit, which tends to feed financial and real instability.

The present work is the starting point of a broader research agenda. In the very next works we would like to investigate other blocks of the model that, for space and tractability reason, remained on the background in the present work. The model will then be used for a normative purpose to test different policy and institutional settings. Among them, some are particularly relevant such as those relating to the regulation of the labor market for their potential impact on demand and investment patterns. Similarly, the role of public finance and fiscal policies also deserves more attention. Finally, the adoption of a stockflow consistent framework, providing a coherent and fully integrated picture of the real and financial sides of the economy, makes our model a suitable tool to assess the impact of monetary, micro-prudential, macro-prudential policies, as well as the opportunity and efficacy of unconventional policies.

Finally, the framework presented is open to several possible developments and integrations. Some of them are already ongoing, such as the introduction of R&D investment and innovation dynamics in the capital good industry, which would open the possibility for long-term, self-sustained real growth in the model.

The introduction of households' indebtedness, real estate markets, and proper portfolio functions by agents', involving a plurality of financial stocks, such as firms' equities, are further examples of already scheduled integrations to the current framework.

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A Parameters values and Initial Setup

Symbol	Description	Baseline	Sensitivity
g_{SS} : pre-SS	Nominal rate of growth in the SS	0.0075	same
$size_{\Phi_H}$: pre-SS	Number of households	8000	same
$size_{\Phi_C}$: pre-SS	Number of consumption firms	100	same
$size_{\Phi_K}$: pre-SS	Number of capital firms	20	same
$size_{\Phi_B}$: pre-SS	Number of banks	10	same
N_{qt} : SS-given	Number of public servants (constant)	1360	same
N_{c0} : pre-SS	Consumption firms' initial workers	4000	same
N_{k0} : pre-SS	Capital firms' initial workers	1000	same
u_0 : pre-SS	Initial unemployment	0.08	same
μ_N : pre-SS	Productivity of labor in K sector	2	same
$\{\mu_k, l_k\}$: pre-SS	Productivity and capital/labor ratios of	$\{1, 6.4\}$	same
	K		
$\chi_c = \chi_k$: free	Number of potential partners on C and K goods mkts	5	same
$\chi_d = \chi_l$: free	Number of potential partners on	3	same
	deposit-credit mkts		
χ_n : free	Number of potential partners on labor	10	same
	mkt (for each vacant job)		
$\epsilon^{a} = \epsilon^{l}$: free	Intensity of choice in deposit-credit	2.00687	same
a h c	mkts		
$\epsilon^c = \epsilon^{\kappa}$: free	Intensity of choice in C and K goods	1.50515	same
22	mkts	0.1	
ν : pre-SS	Firms' inventories target share	0.1	same
λ : free	Adaptive expectations parameter	0.25	same
<i>θ</i> : free	Labor turnover ratio	0.05	same
μ_{c0} : pre-SS	Initial mark-up on ULC for C firms	0.318857	same
μ_{k0} : pre-SS	Initial mark-up on ULC for K firms	0.075	same
$(\mu_{FN}, \sigma_{FN}^2)$: free	Folded Normal Distribution parameters	(1, 0.0094)	same
τ_{π} : pre-SS	Profit tax rate	0.18	same
$\tau_{\pi} = \tau_i$: pre-SS	Profit and Income tax rates	0.18	same
η : pre-SS	Loans duration	20	same
κ : pre-SS	Capital goods duration	20	same
\overline{r} : SS-given	Target profit rate (Investment function)	0.04345	same
\overline{u} : SS-given	Target capacity utilization (Investment	0.8	same
	function)		
γ_1 : free	Profit rate weight (Investment func-	0.01	0.000 : 0.005 : 0.035
γ_2 : free	Capacity utilization rate weight (In-	0.02	0.000 : 0.005 : 0.040
σ : pre-SS	Firms' precautionary deposits as share	1	0.5:0.1:1.5
$a = a \cdot \text{pre-SS}$	Firms' profits' share distributed as div-	0.9	same
$p_c - p_k$. pre-55	idends	0.0	Same
ρ_b : pre-SS:	Banks' profit share distributed as divi-	0.6	same
il . pro CC	Initial interest rate on loons	0.0075	amo
i_{b0} : pre-55	Initial interest rate on der state	0.0070	same
i_{b0}° : pre-55	Initial interest rate on deposits	0.0025	same
$CR_{\bar{0}}$: SS-given	Initial banks target capital ratio	0.17996	same
LR_0^{\star} : SS-given	Initial banks' target liquidity ratio	0.258026342	same
ς_c : tree	Banks' risk aversion towards C firms	3.92245	1.0 : 1.0 : 8.0
ς_k : tree	Banks' risk aversion towards K firms	21.51335	5.0:5.0:40.0
i_{cb} : pre-SS	CB interest rates on advances	0.005	same

Table 1: Parameters

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Symbol	Description	Baseline	Sensitivity
ι : free	Haircut on defaulted firms' capital	0.5	same
	value		
w_{n0} : pre-SS	Initial wages	5	same
ω : pre-SS	Dole (share of average wages)	0.4	same
v: free	Unemployment threshold in wage revi-	0.08	same
	sion function		
α_1 : SS-given	Propensity to consume out of income	0.38581	same
α_2 : pre-SS	Propensity to consume out of wealth	0.25	same
\overline{i}^b : pre-SS	Bonds interest rate	0.0025	same
\overline{p}^b : pre-SS	Bonds price	1	same

	Households	Cons. Firms		Cap. Firms		Banks		Govt. Central Bank		al Bank	Σ
		CA	KA	CA	KA	CA	KA		CA	KA	
Consumption	-32971.4	+32971.4	0	0	0	0	0	0	0	0	0
Wages	+36800	-25000	0	-5000	0	0	0	-6800	0	0	0
Dole	+1280	0	0	0	0	0	0	-1280	0	0	0
CG on inventories	0	+22.3	-22.3	+3.7	-3.7	0	0	0	0	0	0
Investments	0	0	-5375	+5375	0	0	0	0	0	0	0
Capital Amortization	0	-4974	+4974	0	0	0	0	0	0	0	0
Taxes	-7084.7	-484.8	0	-68.7	0	-39.3	0	+7677.4	0	0	0
Dep. Interest	+200.3	+62	0	+12.4	0	-274.7	0	0	0	0	0
Bonds Interest	0	0	0	0	0	+95	0	-165.9	+70.9	0	0
Loans Interest	0	-388.5	0	-9.7	0	+398.2	0	0	0	0	0
Advances Interest	0	0	0	0	0	0	0	0	0	0	0
Profits	+2367.6	-2208.4	+220.8	-312.8	+31.3	-179.1	+71.7	0	0	0	0
CB profits	0	0	0	0	0	0	0	+70.9	-70.9	0	0
Δ Cash	0	0	0	0	0	0	0	0	0	0	0
Δ Deposits	-600.8	0	-186.1	0	-37.2	0	+824.1	0	0	0	0
Δ Advances	0	0	0	0	0	0	0	0	0	0	0
Δ Reserves	0	0	0	0	0	0	-212.6	0	0	+212.6	0
Δ Gov. Bonds	0	0	0	0	0	0	-284.9	+497.6	0	-212.6	0
Δ Loans	0	0	+388.5	0	+9.7	0	-398.2	0	0	0	0
Δ Total	0	0	0	0	0	0	0	0	0	0	0

 Table 2: Aggregate Transaction Flow Matrix (Initial Situation)

	Households	Cons. Firms	Cap. Firms	Banks	Govt.	Central Bank	Total
Cash	0	0	0	0	0	0	0
Deposits	+80704.1	+25000	+5000	-110704	0	0	0
Loans	0	-52194.4	-1298	+53492.5	0	0	0
Cons. Goods	0	+2997.4	0	0	0	0	+2997.4
Cap. Goods	0	+53863.6	+500	0	0	0	+54363.6
Bonds	0	0	0	+38273.5	-66838.1	+28564.6	0
Reserves	0	0	0	+28564.6	0	-28564.6	0
Advances	0	0	0	0	0	0	0
Net Worth	+80704.1	+29666.6	+4202	+9626.4	-66838.1	0	+57361

 Table 3: Aggregate Balance Sheet (Initial Situation)

B Auto and cross correlations in our experiments



Figure 9: Auto (left) and Cross (right) Correlation in the *Banks' risk aversion scenario*. Data are average correlations and their average standard deviations across Monte Carlo runs for each scenario.



Figure 10: Auto (left) and Cross (right) Correlation in the *Firms' capacity utilization weight scenario*. Data are average correlations and their average standard deviations across Monte Carlo runs for each scenario.



Figure 11: Auto (left) and Cross (right) Correlation in the *Profit rate weight scenario*. Data are average correlations and their average standard deviations across Monte Carlo runs for each scenario.



Figure 12: Auto (left) and Cross (right) Correlation in the *Precautionary deposits scenario*. Data are average correlations and their average standard deviations across Monte Carlo runs for each scenario.