WINTER IS POSSIBLY NOT COMING:
MITIGATING FINANCIAL INSTABILITY IN AN AGENT-BASED MODEL WITH INTERBANK MARKET

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ABSTRACT

We develop a macroeconomic agent-based model to study how financial instability can emerge from the co-evolution of interbank and credit markets and the policy responses to mitigate its impact on the real economy. The model is populated by heterogenous firms, consumers, and banks that locally interact in different markets. In particular, banks provide credit to firms according to a Basel II or III macro-prudential frameworks and manage their liquidity in the interbank market. The Central Bank performs monetary policy according to different types of Taylor rules. We find that the model endogenously generates market freezes in the interbank market which interact with the financial accelerator possibly leading to firm bankruptcies, banking crises and the emergence of deep downturns. This requires the timely intervention of the Central Bank as a liquidity lender of last resort. Moreover, we find that the joint adoption of a three mandate Taylor rule tackling credit growth and the Basel III macro-prudential frame-work is the best policy mix to stabilize financial and real economic dynamics. However, as the Liquidity Coverage Ratio spurs financial instability by increasing the pro-cyclicality of banks' liquid reserves, a new counter-cyclical liquidity buffer should be added to Basel III to improve its performance further. Finally, we find that the Central Bank can also dampen financial in- stability by employing a new unconventional monetary-policy tool involving active management of the interest-rate corridor in the interbank market.

KEY WORDS

financial instability; interbank market freezes; monetary policy; macro-prudential policy; Basel III regulation; Tinbergen principle; agent-based models

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Winter is possibly not coming: Mitigating financial instability in an agent-based model with interbank market

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Abstract

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1 Introduction

In this paper, we develop a macroeconomic agent-based model to study how financial instability can emerge from the co-evolution of interbank and credit markets and the possible policy responses to mitigate its impact on the real economy.

Crises in the banking sector are intermittent phenomena that generally appear after periods of intensive credit growth (Schularick and Taylor, 2012; Gourinchas and Obstfeld, 2012). They usually impose high costs not only to the financial sector but also to the economy at large (Reinhart and Rogoff, 2009). The damaging real effects and the feedback loops of the financial turmoil of 2008 also showed that systemic risks can arise during periods of apparent economic tranquility (Battiston et al., 2012, 2016; Acemoglu et al., 2015), and that neither monetary policy nor micro-prudential regulations are sufficient to smooth systemic financial imbalances.

What are the transmission mechanisms between the banking sector and the real economy? On the one side, banking crises hit real economies via the financial accelerator (Bernanke et al., 2007; Gilchrist and Zakrajšek, 2012; Delli Gatti et al., 2010). On the other side, banking crises and credit supply also depend on liquidity freezes in the interbank market (Freixas et al., 2011; Angelini et al., 2011; Acharya and Merrouche, 2012). Indeed, the facility through which banks can get liquidity affects their credit supply thus dampening or magnifying the financial accelerator dynamics (Cornett et al., 2011; Iyer et al., 2013).

For this reason, the evolving debate on interactions between monetary and macro-prudential policies (see Angelini et al., 2014; Rubio and Carrasco-Gallego, 2014; Paoli and Paustian, 2017, among others) should also be focusing on the co-evolution of interbank and credit markets and their possible impact on financial stability and, more generally, on economic dynamics. For instance, one should better study how the Liquidity Coverage Ratio — one of the levers of the Basel III macro-prudential framework — affects liquidity risk and the supply of bank credit. More generally, macro-prudential and monetary policy should also consider active liquidity management. However, the growing body of literature emerging after the 2008 crisis partially overlooks this issue and does not provide models jointly accounting for liquidity crises, banking stability, and economic dynamics.[1] In particular, do Basel III regulatory tools amplify or reduce the risk of liquidity crises? Can one design a macro-prudential framework that dampens instabilities in both liquidity and credit markets? Should monetary policy "lean against the wind"? What are the effects of this type of policy in the interbank liquidity market? Do we need other tools besides interest-rate policy to avoid liquidity crises?

We try to address these questions extending the agent-based model developed in Popoyan et al. (2017) to include the interbank market.[2] The model describes an economy composed of heteroge-

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[1] To the best of our knowledge, there is no model combining liquidity crises, a regulatory instrument to safeguard banking stability, and economic dynamics. They rather discuss singular aspects: liquidity regulations and financial stability(see Diamond and Kashyap, 2016; Duijm and Wierts, 2016, among others), liquidity crisis and monetary policy (see Berger and Bouwman, 2017; Williamson, 2012; Adrian and Shin, 2009), financial regulations and credit (Kashyap et al., 2014; Cornett et al., 2011), etc.

[2] A direct ancestor of the model is developed in Ashraf et al. (2011) and Ashraf et al. (2017).

neous firms, banks, consumers, government and a Central Bank. Firms and consumers engage in trading relationships in decentralized goods and labor markets. Firms finance production relying on bank credit, whose supply is constrained by macro-prudential regulations. Banks engage in liquidity trading in the interbank market to satisfy liquidity needs arising from liquidity constraints. The Central Bank can supply liquidity in the interbank market; it performs monetary policy applying different types of Taylor rules and imposes a macro-prudential regulatory framework akin to either Basel II or III. Finally, the government performs fiscal policy, bails out banks in case of crisis, and eventually issues bonds to finance the deficit.

Our model belongs to an expanding literature of agent-based macro-models (ABMs; Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008) where the economy is considered as a complex system evolving out-of-equilibrium and where aggregate dynamics arise as an emergent property out of interactions among heterogeneous agents (Farmer and Foley, 2009; Dosi, 2012; Kirman, 2016).[3] In that, ABMs are particularly suited to study credit and liquidity market dynamics where heterogenous agent-specific solvency and liquidity risks affect their interactions and can possibly lead to coordination failures, market freezes and bankruptcy cascades.[4]

Simulation results show that the model endogenously generates interbank market freezes wherein liquidity dries up and interbank interest rates become significantly high. These anomalous situations in turn interact with the financial accelerator possibly leading to firm bankruptcies, banking crises and the emergence of deep downturns. The risk of market freezes in the interbank market requires the timely intervention of the Central Bank as liquidity lender of last resort to curb the negative impacts in other markets. Furthermore, we show that the joint adoption of a three mandate Taylor rule tackling credit growth and the Basel III macro-prudential framework is the best policy combination to stabilize financial and real economic dynamics. We then perform a detailed analysis of the different levers of Basel III and we find that the combination of static and dynamic capital requirements is the most effective in dampening the pro-cyclicality of credit and to stabilize the banking sector and the aggregate economy. On the contrary, the Liquidity Coverage Ratio (LCR) spurs financial instability increasing the pro-cyclicality of banks' liquid reserves. For this reason, we design a new macro-prudential tool which adds a counter-cyclical liquidity buffer to the LCR. The new enhanced LCR now contributes to stabilize fluctuations in the interbank market. Relatedly, we find that active management of the width and symmetry of the interest-rate corridor by the Central Bank is a new unconventional monetary policy tool to dampen financial instabil-

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[3] For critical surveys of macroeconomic agent-based models see Fagiolo and Roventini (2012); Gaffard and Napoletano (2012); Fagiolo and Roventini (2017) and Dawid and Delli Gatti (2018). A discussion of agent-based models from the perspective of the evolution of macroeconomic theory is in Napoletano (2018); Dosi and Roventini (2019). Finally, Haldane and Turrell (2018b,a) discuss the complementarity between agent-based and traditional models in macroeconomics.

[4] For macroeconomic agent-based models with integration of credit and financial markets see Alexandre and Lima (2017), Assenza et al. (2015), Bookstaber et al. (2017), Caiani et al. (2016), Ashraf et al. (2017), Catullo et al. (2017), Dosi et al. (2010, 2013, 2015, 2018), Delli Gatti et al. (2005, 2010), Fagiolo et al. (2017a), Gross and Población (2017), Gai et al. (2011), Gurgone et al. (2018), Klimek et al. (2015), Krug et al. (2015), Krug (2018), Lengnick et al. (2013), Montagna and Kok (2016), Napoletano et al. (2015), Poledna et al. (2014), Riccetti et al. (2018), Russo et al. (2016), Raberto et al. (2012), Seppecher and Salle (2015), Sakiyama et al. (2016), Teglio et al. (2012), van der Hoog (2018).

ity. Generally, our results support the Tinbergen principle: an adequate number of instruments is required to control inflation and to achieve stability in both interbank and credit markets.

The rest of the paper is organized as follows. Section 2 describes the model. The results of policy experiments are reported in Section 3. Finally, Section 4 concludes.

2 The model

The model builds on Popoyan et al. (2017) and Ashraf et al. (2017) and is populated by N agents, which can be workers (denoted by subscript z) or shops (denoted by subscript i), and by M banks (denoted by subscript m). In addition, the model includes a government managing fiscal policy and a central bank that sets monetary and macro-prudential policies. In the model, n different types of non-perishable goods can be produced with n types of labor. Each agent (described by subscript z) is characterized by a vector $(i, j, j+1)$, where i describes the good the agent can produce, and j and $j+1$ stand for the agent's primary and secondary consumption goods respectively.[5] Each agent is also endowed with one unit of labor i and cannot consume the good is able to produce (i.e., $i \neq j$ and $i \neq j+1$). This introduces the motivation for trade in the model and the existence of shops, which combine both production and trading functions (see also Howitt and Clower, 2000). Shops finance production with their stock of liquid assets and then, if it is not enough, with credit. Loans to shops are made with full recourse and are collateralized by inventories. Banks provide credit to shops according to risk evaluation and macro-prudential regulation and accept deposits. Banks manage their liquidity by exchanging funds in the interbank market. Finally, liquidity matching in the interbank market is managed by a central clearing counterparty (CCP, see also section 2.5 below).

Figure 1 provides a stylized representation of the model. In what follows we briefly describe the main features of the model and we refer the reader to Appendix A and to Popoyan et al. (2017) for more details.

2.1 The timeline of events

The real and financial side of the economy are linked by multiple, non-linear feedbacks, and evolve in a finite time horizon, indexed by $t = 1, ..., T$. Each period corresponds to a week. In every period t, the following sequence of events takes place:

1. policy variables (e.g., baseline interest rate, sales tax rate, etc.) are fixed;
2. new shops enter the market;
3. wages and prices are fixed;
4. search and matching occur in the goods and labor markets;

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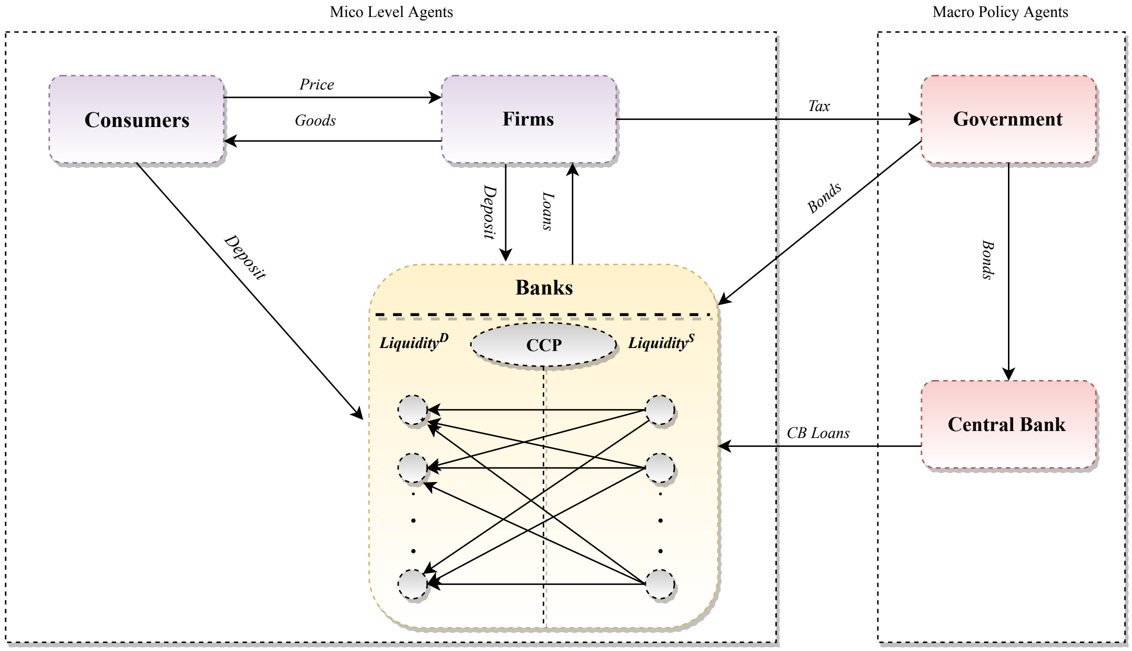
[5] As there is one agent for every single type of good, the number of agents is equal to $N = n(n-2)$.

Figure 1: Structure of the model with interbank market



5. trading in labor and good markets occur;

6. trading in financial and interbank markets occur;

7. bankrupted shops exit and troubled banks are recapitalized.

At the end of each time step, aggregate variables (e.g., output, inflation, unemployment, etc.) are computed, summing over the corresponding microeconomic variables.

2.2 The goods and labor markets

At the beginning of each period, each worker can decide to open a shop with probability $\theta/(N)$ $(1 \leqslant \theta \leqslant N)$. If given the setup costs (S) entry is profitable and she is able to find both potential employees and workers, the shop opens and the worker becomes a "shop owner" (see Appendix A for a detailed description.). Given the entry and exit process, the number of shops in the economy change over time.

Trading in labor market starts with shops fixing the wage (w). A shop confirms its workers unless its labor input exceeds its target and the ratio of inventory-to-sales target (IS) exceeds the critical threshold. Employees keep on working for a shop as long as the wage they get is higher than their effective wage (w_t^{eff}). Moreover, a worker who is either employed or unemployed may also engage in the search for a new job with probability σ $(0 \leq \sigma \leq 1)$. She sends a demand to a randomly selected shop producing the same type of production good as the one they can produce. The searching agent is hired if a job vacancy is open and the effective wage of the job searcher is less than the wage offered by the shop owner.

Trading in goods market starts with consumers learning the selling price (p_s) at the stores they know and placing an order for certain amount (c_s) which satisfies their preferences subject to their budget constraint (see also Section 2.3 below). If inventories of a shop are enough, the order is fulfilled, and the consumer pays the price p_s^{eff}. Agents can also search for new shops where to buy goods. More specifically, they will ask the price to a randomly chosen shop producing the same type of good they like, and they will then select it if its price is lower than the one they currently pay. Finally, agents adjust their balance sheets and fix their planned consumption expenditures once search and matching activities are closed.

2.3 Budget planning and portfolio choices

All agents, i.e., shop-owners, workers, bank owners, engage in consumption smoothing. They first adaptively compute their expected permanent income ($Y^p_{z,t}$; see Appendix A for details), and then they set planned consumption ($CE_{z,t}$) as a fixed fraction of the sum of past financial wealth ($A_{z,t}$) and of expected permanent income:[6]

$$CE_{z,t} = \upsilon(A_{z,t} + Y^p_{z,t}). \tag{1}$$

Consumption is subject to a cash-in-advance constraint. If an agent's financial wealth is high enough, then the agent satisfies her consumption plans and saves the residual. Otherwise, consumption is constrained by the level of the agent's financial wealth.

Once consumption needs are satisfied, agents with positive financial wealth allocate it among different assets taking into account the cash-in-advance constraint. This choice is different according to the agent's status (worker, shop owner, bank owner). The post-consumption wealth of workers is allocated to bank deposits. The saving strategy of a shop owner, is similar to a worker's one, except for the fact that she may need first to repay the credit obtained from banks to finance production. Finally, the portfolio choice of a bank owner depends on the financial condition of her bank: if the bank is "troubled", that is it violates regulatory constraints (see also Section 2.4), wealth will be employed to increase bank's equity; otherwise, it will be deposited.

2.4 Banks and credit supply

Banks gather deposits and provide credit to shop owners to finance their production plans. Besides, they can also lend/borrow from other banks in the interbank market or from the Central Bank to manage their liquidity. The balance sheet structure of banks is presented in Figure 2. The asset side of a bank's m balance sheet is composed of cash reserves held at the central bank H^b_m, loans granted to shops L^s_m, Government bonds B^b_m, collaterals SC^b_m seized from defaulted shops (see Equation 8 below), and interbank loans to other banks IB^a_m. Liabilities include deposits D^s_m and

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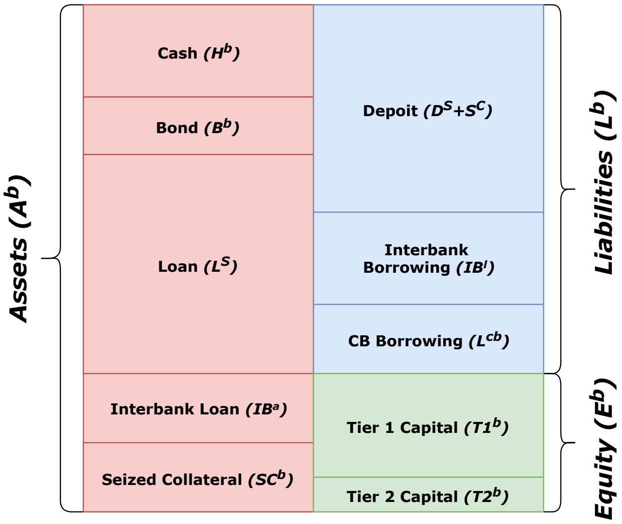
[6] Note that the financial wealth of a worker is the sum of his stock of cash, bank deposits and of the fair value of inventories (if any). For a shop owner, financial wealth is composed by the sum of the stock of cash and bank deposits less outstanding loans. For a bank owner financial wealth is formed by cash on the bank's account plus the value of equity minus the amount of regulatory capital.

Figure 2: The balance sheet of a bank in the model



D^c_m, loans provided by the Central Bank L^{cb}_m and interbank market debt IB^l_m. Naturally, the main balance sheet identities hold in the model (see also Table 4) and the value of bank's equity, E^b_m, is equal to the value of bank's assets minus liabilities.

Banks satisfying regulatory capital requirements (cf. Section 2.6) can provide credit to shops and set their supply according to a reserve of exposures constraint:

$$L^{sup}_{m,t} = \frac{1}{\epsilon_u} E^b_{m,t} - (\psi_L L^s_{m,t} + \psi_{SC} SC^b_{m,t} + \phi_{IB} IB^b_{m,t}), \tag{2}$$

where u captures the macro-prudential policy scenario (respectively $u = 2$ for Basel II, and $u = 3$ for Basel III) and ϵ_b is the minimum capital requirement. Notice that $(\psi_L L^s_{m,t} + \psi_{SC} SC^b_{m,t} + \phi_{IB} IB^b_{m,t})$ represents the bank's total exposure to credit risk.

Bank screens credit applications from shops and grant credit on the basis of a "6C" approach of creditworthiness (Popoyan et al., 2017). This approach is commonly used in practice to identify the financial vulnerability of the potential clients (see, e.g. Jiang, 2007).[7] In a nutshell, this approach aims at determining whether a credit applicant has enough capital, whether it can generate enough cash-flow to pay the loan back, and whether it can provide enough collateral to guarantee the loan.

More precisely, the bank checks first the *Capacity* of the shop to repay the loan by using the "quick ratio" ($QR_{i,t}$) and the "return on asset" (ROA):

$$QR_{i,t} = \frac{\text{Current Assets-Inventories}}{\text{Current Liabilities}} = \frac{D^s_{i,t} + H^s_{i,t} - I_{i,t}}{L^s_{i,t}} \geq \kappa, \tag{3}$$

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[7] Note that in our version of the "6C" approach, only Capital, Capacity, and Collateral, are used. This is because the remaining three C's (i.e., Conditions, Character, and Common sense) are based on credit grantors historical experience with their clients and thus are highly subjective.

$$ROA_{i,t} = \frac{\text{Net income(after tax)}}{\text{Total assets}} = \frac{\Pi^s_{i,t}}{D^s_{i,t} + H^s_{i,t} + I_{i,t}} \geq \zeta, \tag{4}$$

where H^s_i, D^s_i and $I_{i,}$ are respectively cash and deposits and the value of inventories of shop i, $\Pi^s_{i,}$ are its profits, and $0 < \kappa < 1$ and $0 < \psi < 1$ are parameters set in tune with real world banks' internal managerial practices (see also Table 3 and Appendix B). The *Capital* check is performed by using the "debt-to-equity" ratio (DER):

$$DER_{i,t} = \frac{\text{Total liabilities}}{\text{Equity}} = \frac{L^s_{i,t}}{E^s_{i,t}} \geq \varrho, \tag{5}$$

with $0 < \varrho < 1$.

Finally, firms satisfying the three conditions above undergo the *Collateral* check. As firms in the model have only working capital, their collateral is represented by their stock of inventories. The price of collateral is set applying a constant loan-to-value ratio h to the unit value of inventories, assumed to be equal to their marginal cost of production ($W_t(1 + \pi^*)$):

$$P_{h,t} = hW_t(1 + \pi^*), \tag{6}$$

where h is a constant loan-to-value ratio, W_t is publicly known average wage rate across all shops computed by the Government and π^* is the Central Banks's target inflation rate calculated as the average in the US throughout 1984-2006.

The total size of a loan to a firm is therefore equal to:

$$L^s_{i,t} = P_{h,t}(I_{i,t} + S) = hW_t(1 + \pi^*)(I_{i,t} + S),$$

where S denotes set-up cost of new firms, and $I_{i,t}$ is the value of inventories provided as collateral. Note that the rate h captures the risk tolerance of banks when providing credit to a firm.

Shops that pass *all* the above tests are eligible to receive a loan from a bank. However, if a shop's credit demand is higher than bank's residual credit supply (see Equation 2 above), the shop is credit rationed (Stiglitz and Weiss, 1981).

The bank's lending rate is homogeneous across banks in our artificial economy. Banks fix such a rate by applying an annual spread ($s > 0$) on the nominal interest rate set by the Central Bank (see Eq. 13 below):[8]

$$i^L_t = i_t + s/48. \tag{7}$$

Finally, the deposit interest rate is equal to the central bank interest rate, i.e., $i^D_t = i_t$.

In the model, if a shop cannot repay its debt, it becomes insolvent and goes bankrupt. In that case, as loans are made with full recourse, the bank seizes the deposits and the inventories of insolvent shops up to the amount of the non-paid loan. Seized inventories (SC^b) stay in a bank's

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[8] We calibrate the annual loan spread s to be equivalent to the spread between commercial loans and deposits in the US for the period of 1986-2008.

balance sheet until they are sold in the firesale markets with a firesale price P_f equal to:

$$P_{f,t} = \frac{W_t(1+\pi^*)}{2}. \tag{8}$$

If seized inventories are lower than a granted loan, the bank will experience losses, and it could become "troubled" or even bankrupt if its equity becomes negative. Bankrupted banks are bailed out by the Government, that inject enough sources until the equity satisfies the minimum capital requirement (see Section 2.6 below).[9]

2.5 The interbank market

Besides providing loans to shops in the real sector, banks may also engage in liquidity trading in the interbank market.

Demand and supply of liquidity arising from liquidity requirements are fulfilled either as the desired target (under the Basel II scenario) or as a macro-prudential regulatory constraint (under the Basel III scenario). In particular, banks are required to keep the ratio between high-quality liquid assets ($HQLA$) and expected net cash outflows ($NCOF$) above a given threshold $\bar{l}$ (more on that in Section 2.6 below):

$$l_{m,t} = \frac{HQLA_{m,t}}{NCOF_{m,t}} \geq \bar{l}. \tag{9}$$

The above liquidity coverage ratio is just a desired target of the bank under the Basel II scenario, and there are no penalties if the bank does not comply with that ratio. On the contrary, immediate corrective actions need to be undertaken under the Basel III setup to avoid constraints limiting liquidity management and credit supply.

A bank's demand and supply of liquidity arise from the above liquidity coverage ratio as follows. If $l_{m,t} < \bar{l}$, the bank will demand liquidity, otherwise it will supply funds in the interbank market. It follows that the liquidity supply ($IB^{sup}_{m,t}$) and demand ($IB^{dem}_{m,t}$) of bank m in period t read as:

$$IB^{sup}_{m,t} = \begin{cases} \frac{1}{\bar{l}} HQLA_{m,t} - NCOF_{m,t}, & \text{if } \ l_{m,t} > \bar{l} \\ 0, & \text{otherwise} \end{cases}$$

$$IB^{dem}_{m,t} = \begin{cases} \bar{l} \cdot NCOF_{m,t} - HQLA_{m,t}, & \text{if } \ l_{m,t} < \bar{l} \\ 0, & \text{otherwise} \end{cases}$$

The interbank market is represented as a network of credit exposures among the M banks. Such

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[9] In that case, a new bank owner is chosen among the depositors thus keeping the deposit composition bank unchanged.

a network is captured by the adjacency $m \times m$ matrix IB_t denoting interbank exposures at time t:

$$IB_t = IB_t^{qk} \in R^{m\times m} = \left[\begin{array}{cccc|c} IB_t^{11} & IB_t^{12} & \cdots & IB_t^{1m} & IB(L)_t^1 \\ IB_t^{21} & IB_t^{22} & \cdots & IB_t^{2m} & IB(L)_t^2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ IB_t^{m1} & IB_t^{m2} & \cdots & IB_t^{mm} & IB(L)_t^m \\ \hline IB(A)_t^1 & IB(A)_t^2 & \cdots & IB(A)_t^m & \end{array}\right] \tag{10}$$

Each entry IB_t^{qk} in the matrix corresponds to the amount borrowed by bank q from bank k. Moreover, the elements of row q capture the q bank's liabilities towards the other banks in the market $(IB(L)_t^q)$, while the elements of the k column represent the interbank assets of bank k, i.e. the claims of the k bank to the other banks $(IB(A)_t^k)$.

Similarly to real markets (see, e.g. Lazarow, 2011; BCBS, 2012) we assume that trading in the interbank market is managed by a Central Clearing Counterparty (CCP), that matches demand and supply on a pecking-order basis. First, banks demanding liquidity and those supplying liquidity are sorted in descending order. In this way, the first bank on the demand side is the one with the largest liquidity demand. Likewise, the first bank on the supply side is the one with the largest supply. Next, the first liquidity demander is matched to all liquidity suppliers starting from the bank with the largest liquidity supply, and then moving to the second if demand is not fully matched, etc. The liquidity provided to a bank is subtracted from the total liquidity provided by a supplier. If the interbank market does not fully satisfy liquidity demand, the bank demands the residual to the Central Bank. Finally, once the liquidity demand of a bank is fully matched, the matching algorithm moves to the second bank in the demand's queue and the procedure is repeated. The flow diagram in Figure 3 provides a visual idea of the procedure that we have just described.

As we said above unmet banks' liquidity demands can be transferred to the Central Bank liquidity desk. All the liquidity provided by the Central Bank must be secured against collateral represented by government bonds. It follows that the ability of a bank to get liquidity depends on the amount of unencumbered bonds it has in stock. More precisely, the maximum supply of liquidity by the Central Bank to the bank m reads as:

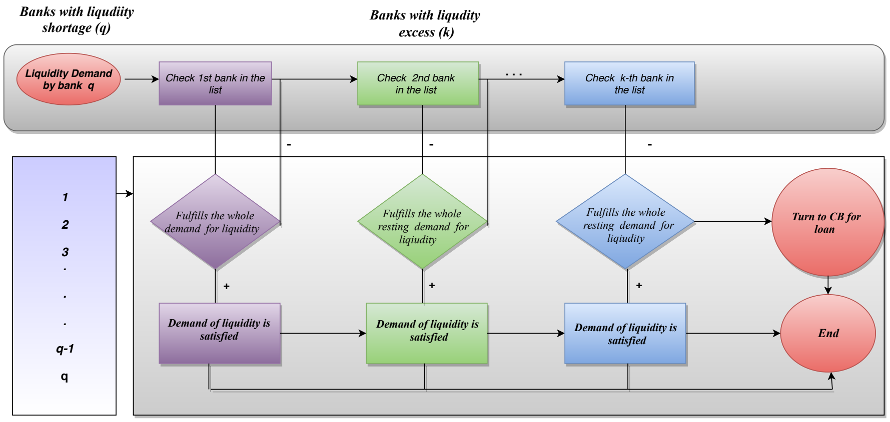
$$L_{m,t}^{CB} = (1 - f)B_{m,t},$$

where f is a haircut rate that is homogeneous across all banks and $B_{m,t}$ is the value of government bonds in bank's m balance sheet. The Central Bank charges an interest rate to the bank that is higher than the one in the interbank market.

If a bank misses enough collateral to meet its residual liquidity demand, then it cannot fulfill the liquidity coverage ratio. Under the Basel III, this implies that the bank will be considered as troubled and therefore unable to supply credit until the requirement is fulfilled again.

For the determination of the interest rate on interbank loans, we follow a framework similar to the one in Poole (1968); Whitesell (2006); Ennis and Weinberg (2007). The central bank sets a

Figure 3: Representation of the matching algorithm in the interbank market



"corridor" for the interest rate charged on its lending and deposit facilities $[i + \phi_l, i - \phi_d]$, where i is the policy rate defined according to the Taylor rule (details in Section 2.6), and $\phi_l > 0$ and $\phi_d > 0$ are the parameters defining the width of corridor. Note that in the case of symmetric corridor (i.e., baseline, narrow and wide) $\phi_l = \phi_d$ while in asymmetric case $\phi_l \neq \phi_d$ and $\phi_l > \phi_d$. The framework is also in line with the real practice of the European Central Bank (Eser et al., 2012). The interbank rate paid by a bank m on interbank loans includes a common component i^{IB}_{corr}, which depends on the excess supply of liquidity in the market and an idiosyncratic risk-premium component. Excess supply for liquidity in the interbank market is defined as

$$\Theta = \frac{\sum_{k=1}^{m} IB^{sup}_{k,t} - \sum_{n=1}^{m} IB^{dem}_{n,t}}{\sum_{n=1}^{m} IB^{dem}_{n,t}}. \tag{11}$$

The common component of the interbank rate will fall in the interval $[i, i + \phi_l]$ whenever $\Theta < 1$. In contrast, $i^{IB}_{corr} \in [i - \phi_d, i]$ if $\Theta > 1$. Finally, $i^{IB}_{corr} = i$ when $\Theta = 1$. The risk-premium component is instead denoted by ε_i, and it is a function of a bank's financial soundness, as captured by its debt-to-equity-ratio: $\varepsilon_i = f(Debt/Equity)$, with $f'() > 0$ (see Constantinides et al., 2002; Caballero et al., 2017). We can summarize the determination of the interbank interest rate charged on the m bank's loans as follows:

$$ib_{m,t}(i, \varepsilon_i, \Theta) = \begin{cases} i + \varepsilon_i(t), & \text{if } \Theta = 1 \\ i + \phi_l - \iota * \Theta + \varepsilon_i(t), & \text{if } \Theta < 1 \\ i - \phi_d + \iota * \Theta^{-1} + \varepsilon_i(t), & \text{if } \Theta > 1 \end{cases} \tag{12}$$

with $0 < \iota < 1$ capturing banks' propensity to lend.

Notice that when the interbank market operates in normal conditions, the interest rate fluctuates in the corridor. However, as we shall show in more detail in Section 3.1 the market can also experience a "freeze" whenever the average interest rate on interbank loans goes above the upper bound of the central bank corridor. Market freezes occur in the model whenever the market has an excess demand for reserves and banks are highly leveraged so that the risk premiums skyrocket in the market. It is worth noticing that such an extreme outcome is a true emergent property of our model, and that it also captures some salient aspects of the interbank markets crisis in 2008.

2.6 Fiscal, monetary and macro-prudential policies

We now describe the policy framework of the model. It includes a Government levying taxes to firms and recapitalizing failed banks, and a Central Bank that manages the interest rate and the associated corridor, and that sets the macro-prudential rules banks must comply with.

Fiscal policy. The Government gathers a sales tax τ from each transaction in the goods market. Collected tax revenues are used to bail out failed banks. If the expenditure for bailouts exceeds tax revenues, the government issues bonds that are bought by banks and (for the remainder, if positive) by the central bank. The tax rate is adjusted at the end of every year considering the dynamics of the debt-to-GDP ratio (see Appendix A for more details).

Monetary policy. The Central Bank performs monetary policy by setting the nominal interest rate i every four weeks ("month") in the simulation dynamics, according to two types of Taylor rule (Taylor, 1993; Howitt, 1992).[10] In the baseline scenario, the Central Bank follows a "dual-mandate" Taylor rule ($TR_{\pi,y}$):

$$ln(1+i_t) = max\{ln(1+i_t^*) + \varphi_\pi(ln(1+\pi_t) - ln(1+\pi^*)) + \varphi_y((y_t - y_t^*), 0\}, \tag{13}$$

where $(1+\pi_t)$ is the inflation in the past 12 months, π^* is the fixed inflation target, φ_π and φ_y are fixed coefficients ($\varphi_\pi > 1$ and $0 < \varphi_y < 1$),[11] y_t is the log GDP, y_t^* is the estimate of log potential output by the Central bank and $i_t^* = r_t^* + \pi^*$, where r_t^* is evolving estimate of the "natural" real interest rate. Having no information about the natural interest rate and the potential output, the Central Bank estimates them adaptively. Accordingly, it adjusts r^* by employing an adjustment speed η_r on the difference between current and target inflation. It then estimates y_t^* using an AR(1) model whose parameters are re-estimated right after r^* is adjusted. In the second scenario, a three-mandate "leaning-against-the-wind" Taylor rule is used ($TR_{\pi,y,c}$), which also takes into account credit dynamics:

$$ln(1+i_t) = max\{ln(1+i_t^*) + \varphi_\pi(ln(1+\pi_t) - ln(1+\pi^*)) + \varphi_y(y_t - y_t^*) + ln(\frac{C_t}{C_{t-1}})^{\varphi_c}, 0\}, \tag{14}$$

with $\varphi_\pi > 1$, $0 < \varphi_y < 1$ and $0 \leq \varphi_c \leq 1$. The presence of credit growth in the Taylor rule, as a barometer of financial imbalances, constitutes the nexus between macro-prudential and monetary policies (more on that in Verona et al., 2014; Lambertini et al., 2013).

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[10] For more types of Taylor rules and their interactions with the macro-prudential framework, see Popoyan et al. (2017).

[11] Adjustment parameters on output gap and inflation are set according Taylor's original specification (Taylor, 1993) (see also Woodford (2001)).

In addition to the nominal interest rate, the Central bank also manages the corridor for its lending/deposit facility to banks, thus affecting the fluctuations of the interbank interest rates (see Section 2.5). It does this by tuning the $\phi_l > 0$ and $\phi_d > 0$ parameters (cf. Equation 12) that define the corridor width on the basis of the chosen corridor window scenario: baseline, narrow, wide and asymmetric (for details refer to Section 3.3.2).

Macro-prudential policy. The pre-crisis financial regulation framework focused only on the safety and soundness of the balance sheet of each financial institution. The troubles associated with the global financial crisis of 2007/2008 accelerated the reform of such a framework that is now "macro-prudential", as it looks at the systemic dimensions of risks arising from banks. Macro-prudential policy aims at the following intermediate goals: (i) increasing the resilience of the financial system to systemic shocks; (ii) containing the build-up of systemic imbalances by reducing pro-cyclicality of credit, creating liquidity buffers and restraining the leverage in the system; (iii) reducing structural vulnerabilities in financial system that arise throughout common exposures, interlinkages, and position of individual financial intermediaries (Hanson et al., 2011). The above objectives are the target of the *Basel III* regulatory package (see BCBS, 2011) delivered by the Basel Committee on Banking Supervision (BCBS).

One main goal in this paper is to compare the efficiency of these new regulatory schemes in terms of higher resilience of the banking sector and study their interactions with monetary policy. We start by describing the Basel II scenario, and then we move to the description of each component in the Basel III package. The apex in the expressions of the various regulatory constraints (respectively 2 or 3) indicates whether a regulatory constraint belongs either to the Basel II or to the Basel III framework.

Basel II is the baseline scenario in the model. Such a regulatory framework comprises only the capital adequacy ratio ($CAR2$), requiring banks to keep a level of total capital (TC) at least equal to a fixed 8% of their risk-weighted assets (RWA):

$$CAR^2_{m,t} = \frac{TC_{m,t}}{RWA_{m,t}} = \frac{E(T1)_{m,t} + E(T2)_{m,t}}{L^s_{m,t} + SC_{m,t} + 0,2 * IB_{m,t}} \geq \overline{\epsilon_2}, \tag{15}$$

where RWA corresponds to the sum of assets adjusted each with corresponding risk weights to determine bank's exposure to potential losses.[12] The banks total capital ($TC_{m,t}$) is the sum of Tier 1 ($E(T1)$) and Tier 2 ($E(T2)$) equities. While $E(T1)$ is the core capital, $E(T2)$ represents the supplementary capital, that is earnings form liquidations in firesale market and evaluations.

The *Basel III* macro-prudential framework attempts to reduce systemic risk stemming from financial institutions by introducing global capital requirements and global liquidity requirements. The former focuses on creating a capital cushion for bad times and by limiting excess leverage. The latter aims at creating a liquidity cushion in case of a market liquidity dry-up.

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[12] Following the standardized approach in Basel II and Basel III regulatory setups, loans to shops and seized collateral are weighted with 100%, cash, and government bonds are assigned zero risk weight, whereas interbank lending is weighted with 20%.

The global capital requirement part is based on three constraints that banks need to comply with: 1) the static minimum capital requirement, 2) the counter-cyclical capital buffer on the top of the latter, 3) the leverage ratio.

1. The *static minimum capital requirement ($CAR3$)* improves on $CAR2$ as it focuses on the high-quality components of banks' capital, i.e., the core capital Tier 1, composed by equity capital and net profits, taken as a ratio of total capital:

   $$CAR^3_{m,t} = \frac{Tier1_{m,t}}{RWA_{m,t}} = \frac{E(T1)^b_{m,t}}{\psi_{IB} IB_{m,t} + \psi_L L^s_{m,t} + \psi_{SC} SC_{m,t}} \geq \overline{\epsilon_3},$$

   where $\overline{\epsilon_3} = 4.5\%$.

2. The *counter-cyclical capital buffer (CCB)* is added to the $CAR3$ with the aim of preventing excess aggregate credit growth (see Borio and Zhu, 2012; Shim, 2013; Hessou et al., 2017). In our model, the CCB is computed in three steps: (i) we calculate the credit-to-GDP ratio; (ii) we estimate the credit-to-GDP gap as the difference between the current credit-to-GDP ratio and its long-run trend;[13] (iii) we calculate the capital buffer add-on as a function of the credit-to-GDP gap according to the following expression:

   $$\kappa = CCB_{m,t} = \begin{cases} 0, & \text{if } G_t < J \\ \frac{(G_t - J)}{(H - J)} * 0.025, & \text{if } J \leq G_t \leq H \\ 0.025, & \text{if } G_t > H \end{cases}$$

   where $0 \leq \kappa \leq 0.025$. Notice that the size of the buffer (expressed in a percentage of risk-weighted assets) is zero when the credit-to-GDP gap (G_t) is under the ("safe") threshold J. Above this floor the buffer add-on increases with credit-to-GDP gap until the latter reaches the ceiling H.[14] Then it remains constant at the upper bound of 2.5%.

3. The *leverage requirement (LR)* is meant to restrain excess leverage in the banking sector, thus providing a further layer of protection against excessive risk-taking by banks (Dermine, 2015; Jarrow, 2013):[15]

   $$LR_{m,t} = \frac{Tier1_{m,t}}{TotalAssets_{m,t}} = \frac{E(T1)^b_{m,t}}{L^s_{m,t} + SC^b_{m,t} + B^b_{m,t} + H^b_{m,t} + IB_{m,t}} \geq \overline{\alpha},$$

   with $\overline{\alpha} = 3\%$.

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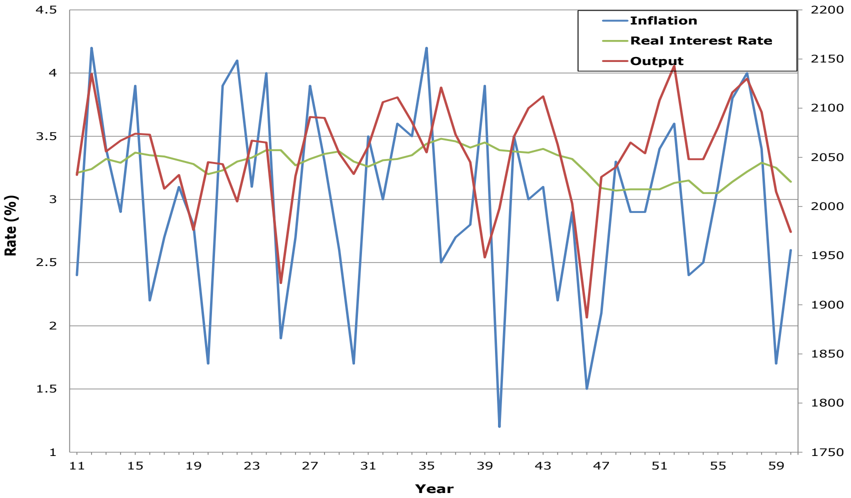
[13] We assume that credit-to-GDP follows a linear trend based on an OLS estimate of 5 years. The regression coefficients are updated recursively using the previous data from the beginning of the observation period (5 periods) until the end of 60 years. The trend forecast is conducted on yearly bases.

[14] The empirical analysis based on banking crisis historical data held in BIS evidence the sensitivity and robustness of adjustment factor $J = 2$ and $H = 10$.

[15] The results of the policy mix and efficiency of leverage requirement in many ways repeat the policy conclusions of Popoyan et al. (2017), and thus absent policy results in the main body of the paper to facilitate the readability of results while presented in Appendix D.

Figure 4: The time series of output, inflation and real interest rate (50 years).



The global liquidity requirement is achieved in the Basel III framework via the *liquidity coverage ratio (LCR)* introduced in Section 2.5, cf. Eq. 9. The main objective of the LCR is to promote liquidity resilience by requiring banks to hold enough unencumbered high-quality liquid assets ($HQLA$) to withstand a stress scenario of cash outflows $NCOF$ over four weeks. In Basel III the liquidity coverage ratio ($\bar{l}$) should be equal to one. This implies that the level of high-quality assets must fully meet the level of net expected cash flows.[16] Thus, a relevant difference between Basel II and Basel III frameworks is that the latter also focuses on banks' liquidity profiles.

3 Simulation results and policy experiments

Similarly to other agent-based models, the high-dimensionality of the dynamical system representing the economy prevents one from obtaining a closed form solution for state variables. Thus, we analyze the model via computer simulations by running extensive Monte Carlo simulation experiments composed of 150 independent runs, whose time span covers sixty years. The values of the parameters of the model are spelled out in Table 3 in Appendix B.

Before employing the model to investigate interactions between macro-prudential and monetary policies, we evaluate its ability to replicate a wide set of macroeconomic stylized facts in the benchmark scenario (for a discussion of empirical validation of agent-based models, see Fagiolo et al., 2017b). For this reason, Figure 4 shows the time series of inflation, interest rate, and output generated by the model in a typical simulation.[17] Furthermore, like its predecessor Popoyan et al.

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[16] Basel III also distinguishes between different types of high-quality assets that enter in the calculation of liquidity coverage ratio. In Appendix A we provide more details about these asset groups and the determination of the liquidity cover ratio in our model.

[17] The time series are depicted from the 11th year since the first 10 years are accounted as transient because of the learning process. Vertical left axis measures real interest rate and inflation, while the right horizontal the aggregate output.

(2017), the model is able to replicate a wide array of macroeconomic stylized facts, ranging from the volatilities and cross-correlation structure of the main macroeconomic variables, to the emergence of empirical regularities such as like the Okun's law and the Phillips curve.[18]

Finally, the presence of the interbank market allows us to study how the financial instability originated by credit relationships among banks impact on credit to firms and thus on the performance of the whole economy. In the next section, we focus on the possible emergence of liquidity freezes in the interbank market. Then, in Sections 3.2, we analyze the impact of different macroprudential and monetary policies on financial and economic stability. Finally, we design and test the impact of new policies tools targeting liquidity fluctuations in the interbank market (cf. Section 3.3).

3.1 The anatomy of liquidity freezes in the interbank market

Our model endogenously generates interbank liquidity freezes. This is for instance shown by the evolution of interbank rates through 50 years, plotted in Figure 5. In normal times, the interbank interest rate dynamics closely follows that of the Central Bank policy rate. The Central Bank is thus able to transmit monetary policy impulses to the whole economy via the interbank market rate. Nevertheless, the interbank interest rate dynamics is also punctuated by large positive spikes corresponding to liquidity freezes. The latter occurs whenever banks with excess liquidity decide to hoard it instead of lending to banks in a shortage of liquid assets (see Section 2.5 above).

Figure 6 takes a more in-depth look at the anatomy of one of these freezes, by plotting the dynamics of the interbank rate in the 42nd year together with the Central Bank policy rate, the lower and upper bound of the corridor and the dynamics of excess supply in the interbank market. In the presence of excess demand for liquidity (corresponding to negative values of the excess supply), the interest rate skyrockets. It follows that interest spikes result from a large unsatisfied demand for liquidity in the interbank market, in line with the dynamics observed during the 2008 financial crisis.

Furthermore, to better understand the effect of the Central Bank's lending facility on interest rates, we also run a counterfactual simulation experiment where the bank is prevented from intervening during interbank market freezes. As Figure 7 shows, the absence of the Central Bank's liquidity backstop facility puts the interbank interest rate on an irreversible explosive dynamics as soon as an excess demand for liquidity passes a critical tipping point. It follows that the lending and deposit facility of the Central Bank is fundamental to allow the interbank market to recover from a liquidity freeze, thus transmitting monetary policy impulses and preventing financial instability from affecting credit, and via the financial accelerator, the real economy.

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[18] We refer the reader to the Popoyan et al. (2017) for a complete discussion of the different macroeconomic stylized facts replicated by our model. Naturally, the empirical validation results are also available from the authors upon request.

Figure 5: Interbank rate dynamics through 600 months

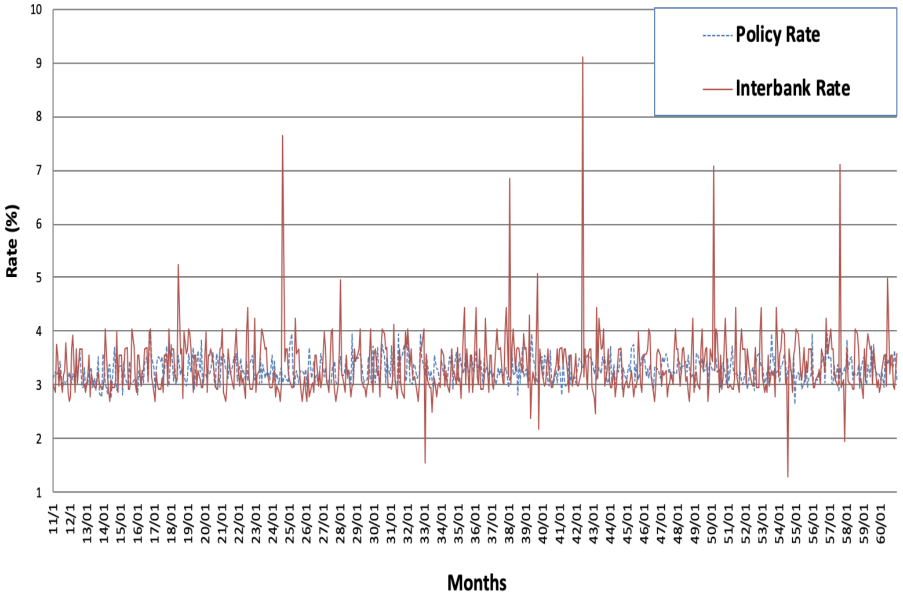


Figure 6: Interbank rate dynamics and excess supply in 42nd year

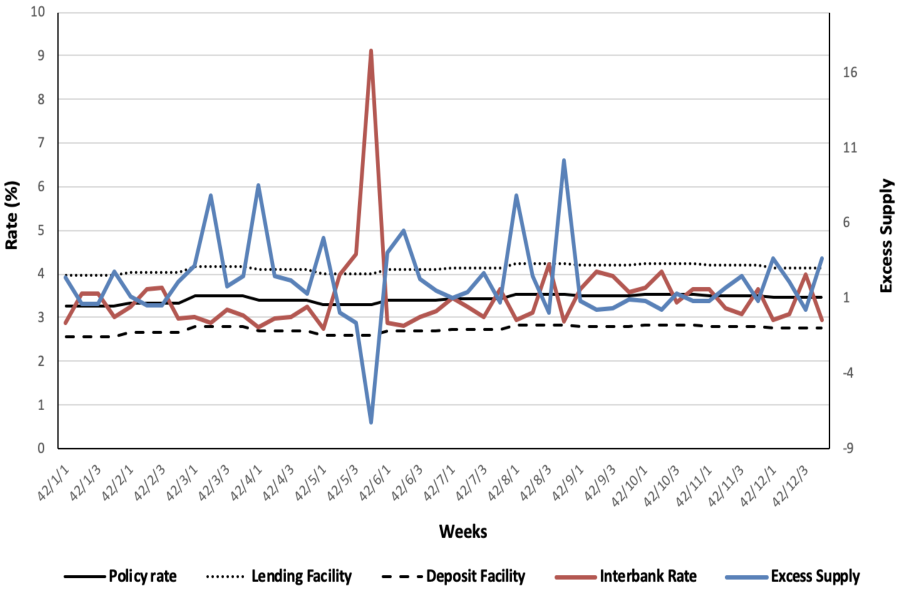
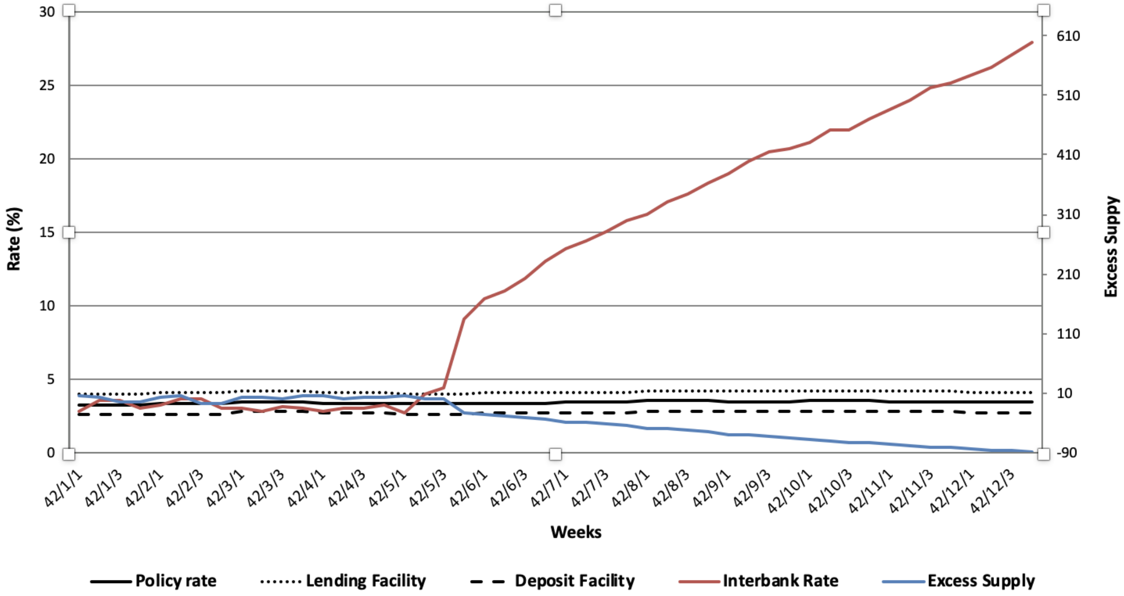


Figure 7: Interbank rate dynamics and excess supply in 42nd year when Central Bank does not act as lender of last resort.



3.2 Macro-prudential and monetary policy interactions

Let us now analyze the interactions between monetary and macro-prudential policies. The bar plots in Figures 8a and 8b provide an overview of the macroeconomic impact of different policy combinations. In addition, the radar plots in Figures 9a and 9b show the impact of the same combinations of monetary and macro-prudential rules on several dimensions capturing the vulnerability of the banking sector. Notice that larger (smaller) polygons in these figures indicate a more (less) vulnerable financial sector (see Aikman et al., 2017, for more details).[19]

Figures 8 and 9 indicate that the Basel III framework improves the macro performance of the economy and stabilize the banking sector. In particular, it has a significant impact on the output gap (see the Figure 8a), the average unemployment (Figure 8b), the likelihood of economic crises, and the bank failure rates, that are lower than in the Basel II setup (details in Appendix D). At the same time, not all levers of Basel III have a positive impact on financial and macroeconomic dynamics. In particular, both the bar and radar plots reveal that the standalone implementation of either static liquidity (LCR) or capital (CAR3) requirements produce worse performances than in the Basel II scenario for all kind of monetary policy rules considered. Only the introduction of counter-cyclical capital buffers (CCB), can compensate for the adverse effects of static capital and liquidity requirements. Indeed, the introduction of such a dynamic buffer improves both the macro performance and financial stability as compared to standalone CAR3 and LCR. Moreover, the results delivered by CAR3 + CCB setup (especially in case of dual-mandate Taylor rule) are not far away from the Basel III one. The latter finding supports the claims in Haldane (2012) and

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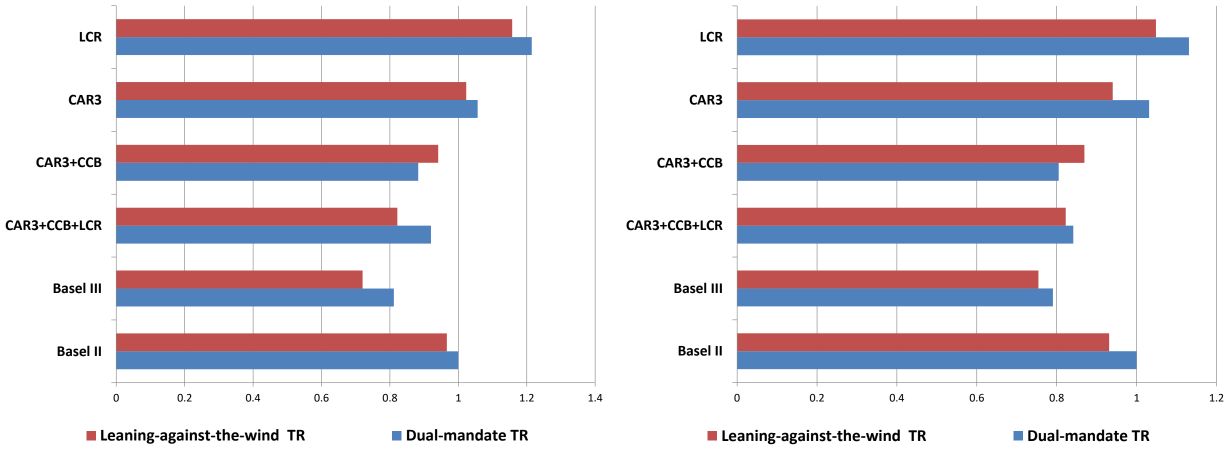
[19] Finally, the tables in Appendix D complement these findings by providing results also for the likelihood of macroeconomic crises, as well as for interactions with the different corridor regimes explored in the previous section.

Figure 8: Bar plot comparison of normalized values of macroeconomic variables across different monetary policies and macro-prudential tools



(a) Output Gap

(b) Unemployment

Note: The figure presents bar charts of the six components of macro-prudential regulation. Blue bar: dual-mandate Taylor rule (TR); red bar: "leaning-against-the-wind" (TR). Each data point is normalized with respect to the Basel II baseline scenario.

Aikman et al. (2014), which advocate for simpler regulatory rules.

As far as specific monetary rules are concerned, Figures 8 and 9 show that a leaning-against-the-wind monetary policy outperforms, a dual-mandate Taylor rule in most scenarios, by generating both better macroeconomic performance and a less vulnerable banking sector.

The above results point in general to the high complementarity between monetary policy and macro-prudential policies in delivering both a more stable macroeconomic and banking dynamics (Brunnermeier and Sannikov, 2016). This indicates the absence of a potential conflict between price and financial stability faced by Central Banks (see, e.g. Howitt, 2011). Moreover, our results are in line with the *Tinbergen rule* (see Tinbergen, 1964) dictating that policy-makers require as many instruments (in this case two: interest rate policy and macro-prudential regulation) as objectives (macroeconomic and financial stability) for effective policy results.[20]

To shed light on the mechanisms generating the results on monetary and macro-prudential interactions, we report in Table 1 the dynamic cross-correlations between GDP and total credit on the one hand, and the main regulatory levers of Basel III (LCR, CAR3, CAR3+CCB) on the other hand.[21] The table reveals first the presence of a financial accelerator at work in our model.

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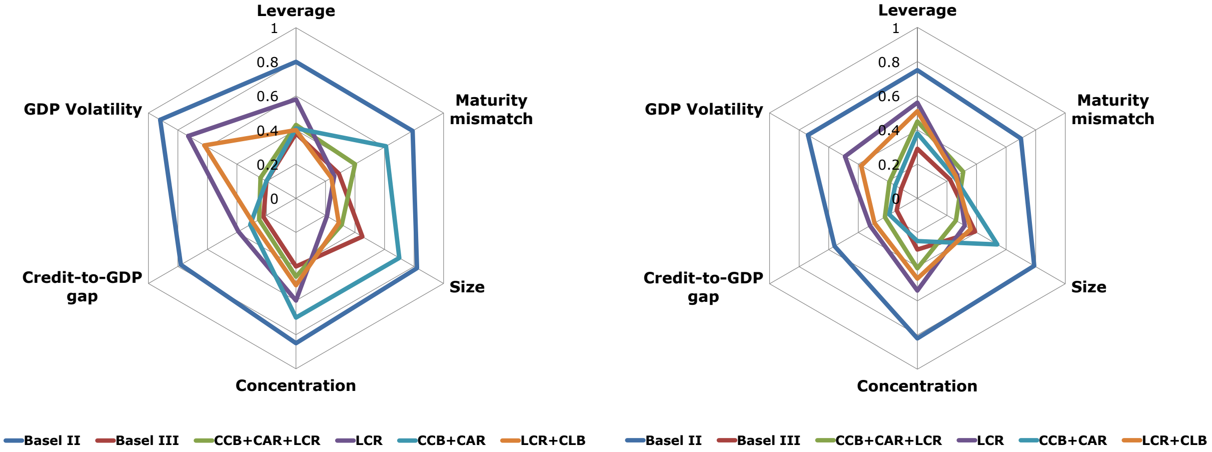
[20] One important exception to the above general pattern is represented by the interaction between the leaning-against-the-wind monetary rule and the counter-cyclical capital buffer (CCB). Figures 8a and 8b indeed reveal that the joint use of dynamic capital requirements and the three-mandate "Leaning-against-the-wind" delivers a worse macroeconomic performance than the combination of CCB and Dual-mandate Taylor rule. This result is in line with Aiyar et al. (2014) and it stems from the excess credit contraction generated by the joint adoption of two policy instruments sharing the same objective, i.e., reducing the pro-cyclicality of credit.

[21] We report results only for the leaning-against-the-wind Taylor rule scenario. However, results are similar under the dual-mandate Taylor rule.

Figure 9: Radar plot of financial vulnerability of banking sector in dual-mandate and "leaning-against-the-wind" Taylor rule.



(a) Dual-mandate Taylor rule

(b) "Leaning-against-the-wind" Taylor rule

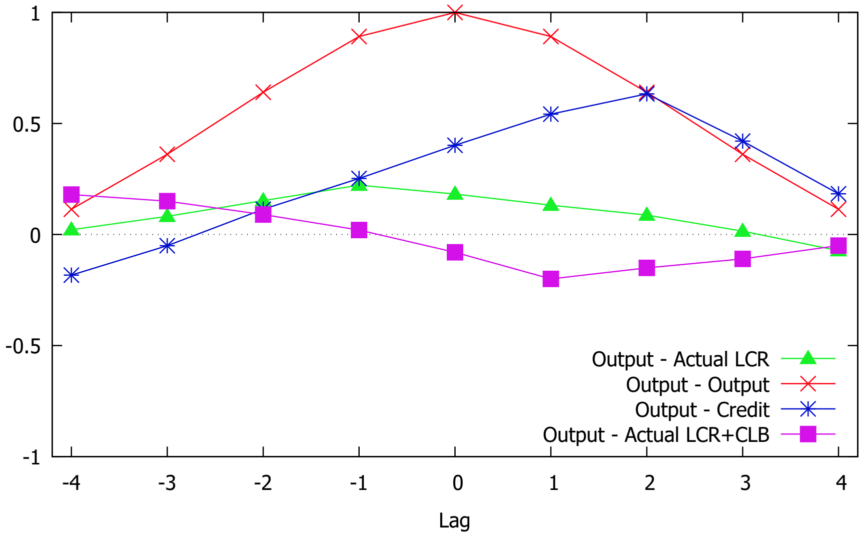
Note: The figure presents radar charts of the six components underlying six indexes of financial vulnerability. Radar is within the five color categories representing standalone financial regulation tools and combination between them. Bank leverage is measured as bank assets to capital; maturity mismatch is loan-to-deposit ratio; size of financial sector is computed as the ratio between financial sector assets to GDP; concentration measure is the ratio between assets of top 5 banks and assets of the whole financial system.

Table 1: Cross-correlation structure of output, credit and financial regulation tools

Variable	t-3	t-2	t-1	t	t+1	t+2	t+3
GDP	0.3612	0.6407	0.8916	1.0000	0.8916	0.6407	0.3612
Tot. Credit	-0.0504	0.1140	0.2526	0.4017	0.5419	0.6331	0.4204
LCR	0.0821	0.1524	0.2219	0.1824	0.1321	0.0874	0.0151
CAR	0.0821	0.1524	0.2219	0.2924	0.2321	0.1574	0.0551
CAR+CCB	0.2144	0.1405	0.0452	-0.0854	-0.1721	-0.2323	-0.1584

Note: Cross-correlations are computed for the LAW - "leaning-against-the-wind" monetary rule.

Figure 10: Counter-cyclical liquidity buffer and credit pro-cyclicality



Autocorrelation of output together with cross-correlations between output and credit or LCR+CLB. Simulated series have been detrended with HP filter ($\lambda = 1600$) series. Average cross-correlations from a Monte Carlo of size 100.

Indeed, total credit is highly pro-cyclical and leading. Furthermore, the static capital (CAR3) and liquidity (LCR) requirements are positively correlated with GDP at most leads and lags. It follows that these instruments amplify real fluctuations, as they contribute to reinforcing the credit cycle. In contrast, the combination of static and dynamic capital requirements (CAR3+CCB) is inversely correlated with GDP at positive leads, as these instruments dampen the pro-cyclicality of credit in the model.

3.3 New policy tools for taming interbank market instability

The flexibility and modularity of our agent-based model also allow testing the impact of new policy instruments that can possibly be used to tame instability in the banking sector. We focus on dynamic liquidity requirements and active interest-rate corridor management. The first policy tool can be considered an additional lever of the Basel III macro-prudential framework to mitigate the pro-cyclicality of the static LCR (cf. Section 3.3.1). The second policy measure requires the Central Bank to actively manage the spread between the lending and deposit facilities interest rates, thus restricting or widening the interbank rate corridor with the aim of dampening liquidity fluctuations (see Section 3.3.2).

3.3.1 Dynamic liquidity requirements

In the previous section, we find that a standalone static liquidity requirement is the *worst* macro-prudential tool, as it contributes to amplify the strains produced by credit fluctuations. This goes against the original objective of the LCR to force banks to hold a buffer of liquid assets as a defense against liquidity distress. This logic overlooks possible vicious spirals triggered by the attempts of banks to meet liquidity requirements regardless of the credit cycle (see, e.g. Li et al., 2017; Duijm and Wierts, 2016). Indeed, pro-cyclical risk-taking over the financial cycle decreases liquidity buffers in good times to the regulatory minimum. However, a binding LCR forces banks to increase their share of high-quality liquid assets during an economic downswing, thereby reducing the share of corporate and interbank loans (see also Duijm and Wierts, 2016).[22] Such a behavior amplifies credit contractions with the result of increasing firm bankruptcy rates and the share of non-performing loans. In addition, it also reduces the supply of liquidity on the interbank market, thus aggravating liquidity problems of other banks.

Effective liquidity requirements ought to take into account the possible feedback effects existing between liquidity requirements and the credit cycle. To test the validity of this hypothesis, we carry out a simulation experiment, where we complement the static LCR with a *counter-cyclical liquidity buffer (CLB*, which follows the same logic of the CCB capital requirement add-on). More specifically, the CLB takes into account the credit-to-GDP gap G_t, according to the following rule:

$$\mu = CLB_{m,t} = \begin{cases} -0.2, & \text{if } G_t < J \\ \frac{(G_t - J)}{(M-J)} * (-0.2), & \text{if } J \leq G_t \leq M \\ \frac{(G_t - M)}{(H-M)} * 0.2, & \text{if } M < G_t \leq H \\ 0.2, & \text{if } G_t > H, \end{cases}$$

where $-0.2 \leq \mu \leq 0.2$ and $M = (J + H)/2$. Notice that the CLB implies a reduction of the liquidity buffer LCR by 20% whenever the credit-to-GDP gap falls below the minimum threshold J (negative buffer). The same rule implies an extra liquidity buffer that grows as a function of the credit-to-GDP gap until the latter reaches the ceiling H. When the upper threshold is met, the counter-cyclical liquidity buffer add-on increases the LCR by 20%.

The macroeconomic and bank performance delivered by the counter-cyclical liquidity buffer is highlighted by the orange line in the radar plot of Figure 9. The introduction of the CLB allows significant improvements in the stability of the banking sector. Indeed, the performance of a macro-

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[22] Banerjee and Hio (2014) find that under tight liquidity requirement UK banks alter the composition of their assets and liabilities, significantly increasing their share of high-quality liquid assets. The increased stock of HQLA is matched by an almost equal reduction in the share of intra-banks loans.

prudential regulation grounded only on the LCR with CLB is not far (and for some dimensions, better) from the obtained combining static and dynamic capital requirements. The reason for such an improvement is explained by the dynamic cross-correlation plot in Figure 10. The introduction of the CLB makes liquidity requirements negatively correlated with GDP at positive leads. This indicates that liquidity requirements now contribute to dampening the economic and credit cycles, instead of reinforcing them.

3.3.2 Active interbank rate corridor management

In all the policy experiments discussed so far, the Central Bank fixes the interest rate (i) according to some form of Taylor rule and then determines the interest rates on lending and deposit facilities by applying a symmetric mark-up and mark-down ϕ to the policy rate. This determines the corridor wherein the interbank rate fluctuates. What happens if the size of the corridor shrinks, growth, or it becomes asymmetric? More generally, can the Central Bank use the width of the corridor to stabilize financial and economic dynamics? This is what we study in our last battery of policy experiments. More specifically, we consider four scenarios for the interest rate corridor: “baseline”, “narrow”, “wide” and “asymmetric”:

1. Baseline corridor: $[i_t - 0.7\%, i_t + 0.7\%]$,
2. Narrow corridor: $[i_t - 0.5\%, i_t + 0.5\%]$,
3. Wide corridor: $[i_t - 1\%, i_t + 1\%]$,
4. Asymmetric corridor: $[i_t - 0.2\%, i_t + 0.6]$[23].

A detailed account of the results of experiments simulating the impact of monetary and macro-prudential policy mix under the above corridor regimes is provided in Appendix D. We find that, in most combinations of macro-prudential and interest-rate rules, an asymmetric corridor regime together with a narrow corridor yields better macroeconomic performance.

What are the mechanisms driving such results? The corridor system should help to reduce the volatility of overnight interest rates, by keeping them close to the policy rate and eliminating any chance of persistent upward or downward biases (Lee, 2016). Indeed, highly volatile overnight interest rates can jeopardize financial stability and the effective implementation of monetary policy, with the result of exacerbating macroeconomic fluctuations. Table 2 reports the ratio between the average volatility of the interbank interest rates, the output gap and the inflation rate in the different corridor scenarios. A value higher than one in the table indicates that the volatility is higher in that specific scenario vis-á-vis the benchmark one. The table suggests that widening (narrowing) the interest rate corridor has a destabilizing (stabilizing) effect on all aggregate variables considered. Besides, introducing an asymmetric corridor also has a positive impact on the interbank interest

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[23] Note that our choice to rely on a particular type of asymmetry, in our case wide credit facility and narrow deposit facility, is motivated by real-world practical setups (e.g., Turkey, EU under floor operating system).

Table 2: Normalized values of volatilities in interbank rate, output gap and inflation for different corridor scenarios.

	Baseline	**Wide**	**Narrow**	**Asymmetric**
Interbank interest rate	1	2.8581^{*} (0.1674)	0.7641^{**} (0.0901)	0.7204^{***} (0.0875)
Output gap	1	1.6093^{**} (0.0594)	0.9115^{*} (0.0688)	0.8702^{**} (0.6421)
Inflation rate	1	1.0351^{*} (0.0784)	0.9873^{***} (0.1014)	0.9805^{*} (0.0946)

[a] *Note:* Absolute value of the simulation t-statistic of H0: "no difference between baseline and the experiment" in parentheses; (***) significant at 1% level; (**) significant at 5% level; (*) significant at 10% level.

rate as well as on macroeconomic variables. Indeed, all volatility statistics considered are lower in the asymmetric and narrow corridor regime than in the baseline scenario. In the latter regimes, the higher reliance of banks on Central Bank funds implies a reduction in the interbank market volatility. The foregoing results are in line with the recent experience in Turkey (see, e.g. Kara, 2016; Aysan et al., 2014; Alper et al., 2013), and suggest that an active interest-rate corridor management can effectively work as additional unconventional monetary measure along targeted macro-prudential policies to reduce the volatility of short-term money market, thus lessening the trade-offs posed by volatile financial flows and improving the macroeconomic environment (see Lee, 2016, for more details).

4 Conclusions

We extended the macroeconomic agent-based model in Popoyan et al. (2017) by adding an interbank market where financial institutions can trade liquidity, and we studied the emergence of market freezes akin to those observed during the 2008 financial crisis. We then used the model to simulate the impact of different combinations of macro-prudential constraints (e.g., Basel II vs. III and the different levers of the latter) and monetary policy rules (dual-mandate vs. leaning-against-the-wind Taylor rules). Finally, we tested the impact of new policy tools involving active interest corridor management or counter-cyclical liquidity buffer.

The model endogenously generates business fluctuations amplified by the financial accelerator mechanism. Moreover, rare interbank market freezes worsen the balance sheets of banks, thus reducing their credit supply and increasing financial instability. In these cases, if the Central Bank does not provide enough liquidity to the interbank market acting as a lender of last resort, the impact on the real dynamics of the economics is significant. The interactions between monetary policy and macro-prudential regulation suggest that the best policy mix involves a "leaning-against-the-wind" Taylor rule accounting for credit dynamics as well, combined with a fully-fledged Basel III framework. This result also confirms the validity of the Tinbergen principle: two instruments (interest rate policy and macro-prudential regulation) are needed to achieve both macroeconomic and financial stability. We also examined in detail the impact of the different regulatory levers of the Basel III framework, and we found that the good performance of the latter mainly stems from the combination of static and dynamic capital requirements. In contrast, a static liquidity requirement, as the one implied by the Liquidity Coverage Ratio (LCR) in Basel III, increases financial instability, as it induces pro-cyclical liquidity management by banks that amplify strains both in the interbank market and in the provision of credit to the real economy. The aforementioned adverse effects of the Liquidity Coverage Ratio can be dampened by coupling the latter with a counter-cyclical liquidity buffer add-on. Finally, we also studied the impact of an active interbank rate corridor management by the Central Bank, and we found that the width and asymmetry of the corridor have important financial stability implications (Li et al., 2017) and could be considered a new unconventional monetary policy tools.

The model can be extended in several ways. First, relying on the dynamic network between firms and banks, one could study how its evolution is affected by different combinations of macro-prudential and monetary policies. Second, one could study how the emergence of too-big-to-fail and too-connected-to-fail banks poses a threat to the stability of financial markets, possibly leading to deep downturns. Relatedly, one could examine specific policies targeting systemically important banks, involving, e.g., extra capital surcharges.

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Appendix A The model

The appendix presents the comprehensive structure of the real side of the model and of the fiscal policy discussed in Section 2 of the paper. We start with the shop entry procedure and the process of price and wage formation. We also discuss in detail the the budget planning and portfolio choices of each type of agent and search-and-matching mechanisms in labor and goods markets. Finally, we present the equations related to fiscal policy as well as the computation of the Liquidity Coverage Ratio.

A.1 The real side of the economy

Shop entry in the model is a two-steps process: first a potential shop owner needs to pay a fixed set-up cost S (expressed in units of shop owner's consumption good) with a stock of available liquid resources (money, deposit, credit).[24] If the potential entrepreneur can afford to pay a setup cost she passes to a profitability test. She randomly chooses the mark-up ($\mu_{i,t}$) and the sales target ($y^{trg}_{i,t}$), and computes the price and the expected profits.[25] The price $p^{nor}_{i,t}$ is equal to

$$p^{nor}_{i,t} = \frac{(1+\mu_{i,t})}{(1-\tau)} w_{i,t}, \tag{16}$$

where τ is the sales tax rate and $w_{i,t}$ stands for the wage rate.

The flow of profit from entry, $\Pi_{i,t}$, is calculated as follows:

$$\Pi_{i,t} = w_{i,t}(\mu_{i,t} y^{trg}_{i,t} - (F-1)) - w_{i,t} i^D_t (y^{trg}_{i,t} + F - 1) > 0, \tag{17}$$

where F stands for fixed cost (expressed in units of type i labor) and $w_{i,t}$ is the wage rate. If $\Pi_{i,t} > 0$, the potential shop owner makes a job offer to an unemployed worker informing her about the wage she is ready to pay. The wage rate is defined as follows:

$$w_{i,t} = W_t (1+\pi^*)^{\frac{\Delta+1}{2}}, \tag{18}$$

where W_t, Δ and π^* are average wage rate across all shops computed as a ration between aggregate wage and aggregate employment at time t, fixed contract period and Central Bank's target inflation rate respectively.[26] The unemployed agent in a job search will accept the offer of shop owner if the proposed wage is more then her effective wage (described in Equation 21 below): $w^{eff}_t < w_{i,t}/(1+\pi^*)$.

In addition, the potential show owner makes an offer to a possible consumer (i.e., a randomly chosen agent whose primary consumption good coincides with the entrepreneur's production good) with the price she will charge for the product. The price that entrepreneur would charge ($p^{nor}_{i,t}$) is defined as follows:

$$p^{nor}_{i,t} = \frac{(1+\mu_{i,t})}{(1-\tau)} w_{i,t}, \tag{19}$$

where $\mu_{i,t}$ is the mark-up and τ stands for tax rate.The potential consumer will accept the shop owner's proposal if the price $p^{nor}_{i,t}$ is less than the consumer's effective price (p^{eff}_t): $p^{eff}_t > p^{nor}_{i,t}/(1+\pi^*)$

Shops during their life will continue setting prices with the normal pricing rule stated in Eq. 19 except when the sales target is too far from shop inventories. More precisely, if the inventory-to-sales ratio rises much above its upper critical threshold (IS) a shop will cut its price by δ_p^{-1}, and on the contrary, it will

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[24] Note that credit is equal to 0 if the agent did not receive a credit in the previous period, and to $P_{h,t}(S + I_{i,t})$ otherwise, where I is the potential entrepreneur's stock of inventories and P_h is the haircut price discussed later in Equation 6.

[25] The mark-up $\mu_{i,t}$ is drawn from a uniform distribution over the support $[0; 2\overline{\mu}]$, where $\overline{\mu}$ is the average percentage mark-up over variable costs $w_{i,t}$. The latter is extracted from a uniform distribution over $[1; n]$.

[26] The inflation target is set equal to 3% – U.S. average for the period of 1984-2006 period.

push the price up by δ_p if the inventories-to-sales ratio falls below the minimum (IS^{-1}) threshold:

$$p_{i,t} = \begin{cases} p^{nor}_{i,t} * \delta_p, & \text{if } I < y^{trg}_{i,t} * IS^{-1} \\ p^{nor}_{i,t} * \delta_p^{-1} & \text{if } I > y^{trg}_{i,t} * IS \\ p^{nor}_{i,t}, & \text{otherwise} \end{cases}$$

Accordingly the frequency of price changes is endogenous in the model.

The shop fails and exits the market if the value of its outstanding loans is higher than its financial wealth:

$$A^s_{i,t} = H^s_{i,t} + D^s_{i,t} + P_{h,t} * I_{i,t} - L^s_{i,t} < 0$$

A.2 Budget planning and portfolio choices

Agents adjust their permanent income by using the following adaptive rule:

$$\Delta Y^p_{z,t} = \lambda_p (Y_{z,t} - Y^p_{z,t-1}),$$

where Y_z, Y^p_z and λ_p are, respectively, the financial wealth, permanent income, and the adjustment speed parameter.

The financial wealth of a worker is:

$$Y_{c,t} = H_{c,t} + D_{c,t} + P_f * I_{c,t},$$

where $H^{c,t}$ are cash holdings, $D^{c,t}$ stands for bank deposits and $P_f * I_{c,t}$ is the value of inventories in the fire-sale market.

The financial wealth of shop owner is:

$$Y_{s,t} = H^{s,t} + D_{s,t} - L_{s,t},$$

where $H^{s,t}$ are cash holdings , $D^{s,t}$ stands for bank deposits and $L_{s,t}$ are outstanding loans.

Finally, the financial wealth of a bank owner whose bank is not troubled reads as:

$$Y_{b,t} = H_{b,t} + (E^b_{m,t} - \overline{\epsilon_b}(L^s_{m,t} + SC_{m,t} + 0.2IB_{m,t}),$$

In the above expression H^b denotes cash holdings and $(E^b_{m,t} - \overline{\epsilon_u}(L^s_{m,t} + SC^b_{m,t} + 0.2IB^b_{m,t})$ denotes instead the bank's equity after subtracting regulatory capital.[27] .

Let us now consider the portfolio choices of a worker. A worker holds $\overline{H^c_z}$ in cash and $\overline{D^c_z}$ in deposits and must choose the amount of deposits D^c_z and money H^c_z to fund their consumption plans given the constraint:

$$D^c_{z,t} = (1 + i^D_t)(\overline{H}^c_{z,t} + \overline{D}^c_{z,t} - H^c_{z,t}).$$

If $CE_{j,t} \leq \overline{H}_{z,t} + \overline{D}_{z,t}$, then the worker fixes $CE_{z,t} = H_{z,t}$ and leaves the residual in her bank account. Otherwise, $CE_{z,t} = H_{z,t} = \overline{H}_{z,t} + \overline{D}_{z,t}$.

Next consider the budget planning for a bank owner.If the bank owned is troubled, consumption expenditures CE_z are constrained by current cash holdings $\overline{H_z}$. If the cash owned is more than CE_z, the bank owner deposits the difference $\overline{H}_{z,t} - CE_{z,t}$ in her bank account. Otherwise, $CE_{z,t} = \overline{H}_{z,t} = H_{z,t}$. If the bank owned is not troubled and $CE_{z,t} \leq A_{z,t}$, the owner sets $H_{z,t} = CE_{z,t}$ and leaves the difference $A_{z,t} - CE_{z,t}$ in bank equity. Otherwise, $H_{z,t} = CE_{z,t} = A_{z,t}$.

Finally, consider the portfolio management of a shop owner. Except for money (H_z) and deposits (D_z), a shop owner can apply for a loan (L_z). If the shop has already a currently rolling credit and her bank is not troubled, her credit limit will be equivalent to the haircut value of her eligible collateral (determined in

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[27] The balance-sheets of all the types of agents are reported in Table 4 in Appendix C. Notice that the model is stock-flow consistent (see, e.g., the seminal contribution of Godley and Lavoie, 2007).

Eq. 6). Consequently, the financial constraint of a shop owner's is as follows:

$$\begin{aligned}&H_{z,t} - \overline{H}_{z,t} = \overline{D}_{z,t} - \tfrac{D_{z,t}}{1+i_t^D} + \tfrac{L_{z,t}}{1+it^L} - \overline{L}_{z,t},\\ &L_{z,t} \leq P_{h,t}(I_t + S)(1 + i_t^L).\end{aligned}$$

where $H_{z,t} \geq 0$, $D_{z,t} \geq 0$, $L_{z,t} \geq 0$ and where $\overline{H}_z$, $\overline{D}_z$ and $\overline{L}_z$ are respectively, the current levels of cash, deposits, and bank loans. The above-mentioned constraints are met, and the loan is paid if $\overline{H}_{z,t} + \overline{D}_{z,t} + P_{h,t}(I_t + S) \geq \overline{L}_{z,t}$.

A.3 Labor and good market trading

We now turn to describe the search-and-matching algorithms governing interactions in labor and goods markets.

Labor market. The wage of shop is set according to Equation 20. Incumbent shops update their wages at the end of each period. First, shops compute their own sales target $y_{i,t}^{trg}$, by setting it equal to past sales. Then, they update their wages every Δ periods on the basis of the following rule:

$$w = \overline{w}\left[\left(1 + \beta\left(\overline{x^{trg}}/\overline{x^{pot}} - 1\right)\right)(1 + \pi^*)\right]^{\Delta/48}, \tag{20}$$

where $\overline{w}$, $\overline{x^{trg}}$ and $\overline{x^{pot}}$ are correspondingly the current wage, the average input target and potential input covering the past Δ periods, and β is responsible for the degree of wage (and price) flexibility in our artificial economy.

Employees exchange their labor endowment for an effective wage:

$$w_t^{eff} = min(w_{i,t}, H_{i,t}), \tag{21}$$

where H is the cash the shop owner has available. The shop accepts the offer of the worker unless its labor input exceeds its target and the ratio of the inventory-to-sales target (IS) exceeds the critical threshold value $IS > 1$. Shop owners are self-employed, and they use their endowment as an input.

Goods market. Consumers gather information about the selling price of both their primary and secondary consumption goods (p_s, $s = 1, 2$) and, based on their cash-in-advance constraint $pc \leqslant H$, they send orders for the amount c_s. Shops sell an amount $c^{eff} = min(c_s, I)$ considering their level of inventories (I). Consumers pay an effective price equal to $p_s^{eff} = p_s c_s / c_s^{eff}$. Consumers choose their desired consumption bundle $(c_1; c_2)$ to maximize the utility function below subject to $p_1c_1 + p_2c_2 = E$ budget constraint:

$$u(c_1, c_2) = c_1^{\varepsilon/(\varepsilon+1)} + c_2^{\varepsilon/(\varepsilon+1)}, \tag{22}$$

where $\varepsilon > 0$ stands for the demand parameter.

A.4 Fiscal policy

The Government charges a sales tax τ on every transaction in the goods markets. The Government adjusts τ considering the dynamics of debt-to-GDP ratio. In particular, the Government initially estimates its debt relative to annual estimated potential output y^* (corresponding to the level of output in full-employment). Next, it sets the new tax rate equal to τ^* as follows:

$$\tau_t = \tau^* + \lambda_\tau \left(\frac{B_t}{P_t(1 + i_{m,t})(48e^{y^*})} - b^*\right), \tag{23}$$

where B, P, λ_τ and $1 + i_m$ are respectively the total stock of government bonds, the current price level, the adjustment parameter and weekly interest rate. The tax rate in Eq. 23 is the one that leaves the debt-to-GDP ratio stationary in the full-employment equilibrium, plus an adjustment factor based on the difference between the actual debt-to-GDP and targeted b^*.

A.5 Computation of the liquidity coverage ratio

In line with Basel III regulatory accord, we consider both Level 1 and Level 2 of high-liquid assets, $HQLA$, in the computation of the liquidity coverage ratio. Level 1 assets are composed by cash-money H^b_t and by Government bonds $B^b_{m,t}$. Level 2 assets include only interbank loans in our model. They can contribute to $HQLA$ with a haircut of 15% on their value and up to the limit of two-thirds of the value of Level 1 assets.[28] It follows that the expression for $HQLA$ in our model reads as:

$$HQLA_{m,t} = B^b_{m,t} + H^b_{m,t} + \min\left[0.85IB^b_{m,t};\ \ \frac{2}{3} * (H^b_{m,t} + B^b_{m,t})\right].$$

Expected net cash outflows ($NCOF$) are computed by weighting liabilities and assets by the corresponding run-off (for liabilities) and default (assets).[29] Let $\overline{O}^{b^{(-)}}_t$ and $\overline{O}^{b^{(+)}}_t$ indicate the current contractual cash outflows and inflows of the bank. Expected cash outflows, $Ex[O^{b^{(-)}}_t]$, and expected cash inflows, $Ex[O^{b^{(+)}}_t]$, are then calculated as follows:

$$Ex[O^{b^{(-)}}_{m,t}] = \overline{O}^{b^{(-)}}_{m,t} + \sum_{e=1}^{n} \vartheta_e Liab^e_{m,t} = O^-_{m,t} + \vartheta_D(D^s_{m,t} + D^c_{m,t}) + \vartheta_{cb}L^{cb}_{m,t} + \vartheta_{ib}\Delta IB_{m,t}$$

$$Ex[O^{b^{(+)}}_{m,t}] = \overline{O}^{b^{(+)}}_{m,t} - \sum_{a=1}^{n} \vartheta_a Asset^a_{m,t} = O^+_{m,t} - \vartheta^s_L + \vartheta_H H^b_{m,t} + \vartheta_b B^b_{m,t},$$

where $\vartheta_D = 0.1$, $\vartheta_{cb} = 0.25$, $\vartheta_\Delta = 1$ are the run-off rates of liabilities, and $\vartheta^s_L = 0.5$, $\vartheta_H = 0$ and $\vartheta_b = 0.2$ are the default rates of assets as specified in the Basel III accord. Accordingly, $NCOF_{m,t} = Ex[O^{b^{(-)}}_{m,t}] - min(Ex[O^{b^{(+)}}_{m,t}; 0,75 * [O^{b^{(-)}}_{m,t}])$.

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[28] All assets included in the $HQLA$ calculation must be unencumbered (e.g. not pledged as collateral) and operational (e.g. not used as a hedge on trading positions). Finally, Level 2 assets must be limited to 40% of banks total HQLA.

[29] Note that run-off rates of liabilities and default rates of assets are the same for all the banks and are defined by the Basel committee of bank supervision (see BCBS, 2013; Keister and Bech, 2012).

Appendix B Parameters

Table 3: Parameters of the model

Parameter	*Description*	*Value*
	Macro-prudential Regulation Parameters	
$\overline{\alpha}$	Leverage requirement	0.03
$\bar{l}$	Liquidity requirement	1
$\overline{\epsilon_2}$	Minimum capital requirement in Basel II	0.08
$\overline{\epsilon_3}$	Minimum capital requirement in Basel III	0.045
κ	Counter-cyclical capital buffer	$[0, 0.025]$
μ	Counter-cyclical liquidity buffer	$[-0.2, 0.2]$
ϑ_D	Run-off rate of deposit	0.1
ϑ_{cb}	Run-off rate of central bank loan	0.25
ϑ_{ib}	Run-off rate of interbank loan	1
ϑ_L	Run-off rate of commercial loan	0.5
ϑ_B	Run-off rate of gov. bonds	0.2
	Banks Parameters	
κ	Quick ratio	0.5
ϱ	Debt-to-equity ratio	0.5
ζ	Return on assets	0.1
s	Loan spread	0.0175
h	Loan-to-value ratio	0.5
f	Aggregate haircut on collateral to obtain funding form CB	0.1
ι	Propensity to lend	0.7
m	Number of banks	25
	Fiscal and Monetary Policy Parameters	
φ_π	Inflation coefficient in Taylor rule	1.5
φ_y	Output gap coefficient in Taylor rule	0.5
φ_U	Unemployment coefficient in Taylor rule	1.1
φ_c	Credit coefficient in Taylor rule	0.7
π^*	Target inflation rate	0.03
η_r	Adjustment speed of evolving real rate target	0.0075
b^*	Target debt-to-GDP ratio	0.33
λ_τ	Fiscal adjustment speed	0.054
ϕ	Corridor width (baseline,wide,narrow,asymmetric)	$[0.2, 1]$
	Workers/Consumers Parameters	
ε	Demand parameter	7.0
λ_p	Permanent income adjustment speed	0.4
θ	Frequency of innovation	100
σ	Job search probability	0.5
N	Number of population	2400
	Shops Parameters	
$\bar{\mu}$	Average percentage markup over wage	0.138
S	Setup cost	15
IS	Critical inventory-to-sales ratio	3.0
δ_p	Size of price cut	1.017
β	Wage adjustment parameter	0.3
Δ	Length of the contract period	12
n	Number of goods	50

Appendix C The balance-sheet matrix of the model

Table 4: The balance-sheet matrix of the model

	Consumer	*Shop*	*Bank*	*Gov*	*CB*	Σ
Deposit	$+D^c$	$+D^s$	$-(D^c + D^s)$			0
Loans		$-L^s$	$+L^s, -L^{cb}$		$+L^{cb}$	0
Loan-IB			$+IB^b, -IB^b$			0
Bond			$+B^b$	-B	$+B^{cb}$	0
Inventory		$+I, -SC^b$	$+SC^b$			$+I$
HPM	$+H^c$	$+H^s$	$+H^b$		$-H^{cb}$	0
Balance	$-E^c$	$-E^s$	$-E^b$	$+GD$		$-I$
Σ	**0**	**0**	**0**	**0**	**0**	**0**

[a] ***Note:*** *The matrix describes the accounting structure of the model. All rows related to financial assets or liabilities sum to zero except the inventories which are connected to tangible capital.*

Appendix D Model Results: Interaction Tables

Table 5: Macro-prudential and Monetary Policy in Corridor Regime:Normalized Values of Average Output Gap Across Experiments

	Corridor=1		Corridor=0.5		Corridor=0.7		Asymmetric	
	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$
Basel II	1.0000	0.9869*	1.0000	0.9564**	1.0000	0.9664***	1.0000	0.9456*
Basel III	0.9427*	0.8051**	0.7164	0.7054*	0.8115*	0.7201**	0.7011*	0.6994*
CAR3+CCB+LCR	1.1901**	1.1766*	0.8926*	0.8003**	0.9201**	0.8216*	0.8143*	0.7780*
CAR3+CCB+LR	1.2415**	1.2044*	0.9814	0.8436*	0.9647*	0.9436	0.8446**	0.8136*
CAR3+CCB	0.9609*	0.9240*	0.7901*	0.8040	0.8828*	0.9211*	0.8027*	0.8094***
CAR3	1.2614*	1.1318	1.0623**	0.9792*	1.0565*	1.0232**	1.0154	0.9645*
LCR	1.3245	1.2915*	1.1215*	1.0454**	1.2145	1.1574*	1.0515*	0.7243
LR	2.8674	2.6513***	2.3015**	1.9467*	2.6310**	2.4022***	1.8476	1.8236**
LCR+LR	2.5436*	2.3255*	2.0518**	1.9736*	2.6913	2.3137*	1.6794*	1.6076**

^{a}*Note:* (***) significant at 1% level; (**) significant at 5% level; (*) significant at 10% level.

Table 6: Macro-prudential and Monetary Policy in Corridor Regime: Normalized Values of Unemployment Across Experiments

	Corridor=1		Corridor=0.5		Corridor=0.7		Asymmetric	
	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$
Basel II	1.0000	0.9612*	1.0000	0.9304*	1.0000	0.9312**	1.0000	0.9041*
Basel III	0.8125*	0.7745**	0.7413*	0.7196**	0.7906*	0.7542*	0.7671*	0.7406***
CAR3+CCB+LCR	0.9103*	0.8345**	0.8245**	0.7954*	0.8414*	0.8225**	0.8064*	0.7849*
CAR3+CCB+LR	0.9313*	0.9004	0.8613*	0.8336***	0.8847**	0.8496	0.8394	0.8013**
CAR3+CCB	0.8726*	0.8911*	0.7604	0.7648*	0.8051*	0.8694	0.7790*	0.7842*
CAR3	1.1338*	1.0102**	1.0742*	0.9615**	1.0314	0.9802*	1.0204*	0.9548
LCR	1.2748*	1.1784***	1.0504**	1.0415*	1.1311*	1.0984**	1.0465**	1.0330*
LR	1.6739	1.6315*	1.5430**	1.5013	1.6144**	1.5932*	1.4394**	1.4206
LCR+LR	1.5315	1.5046*	1.4835*	1.4806**	1.5051*	1.4838	1.4150**	1.3817*

^{a}*Note:* (***) significant at 1% level; (**) significant at 5% level; (*) significant at 10% level.

Table 7: Macro-prudential and Monetary Policy in Corridor Regime: Normalized Values of Likelihood of Economic Crisis Across Experiments.

	Corridor=1		Corridor=0.5		Corridor=0.7		Asymmetric	
	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$	$TR_{\pi,y}$	$TR_{\pi,y,c}$
Basel II	1.0000	0.9611	1.0000	0.9154*	1.0000	0.9241*	1.0000	0.9012**
Basel III	0.7226*	0.6948**	0.6051*	0.5744***	0.6214*	0.6033*	0.6047*	0.5654*
CAR3+CCB+LCR	0.8322*	0.8196*	0.7862**	0.7751*	0.8114*	0.7816**	0.7780	0.7565*
CAR3+CCB+LR	0.9913*	0.9646	0.8336*	0.8097**	0.8615*	0.8436	0.7815***	0.7636*
CAR3+CCB	0.7643**	0.8107*	0.6507	0.6749**	0.6852*	0.7341**	0.6441*	0.6792*
CAR3	1.0612**	1.0452*	1.0545*	1.0451**	1.0604	1.0192*	1.0284*	0.9849*
LCR	1.4216	1.3702***	1.0757	1.0203**	1.1456*	1.0384**	0.9265*	0.9195**
LR	1.9744*	1.9435	1.7610**	1.7412*	1.8246*	1.7894**	1.6942***	1.6043
LCR+LR	1.8615	1.8236*	1.7015*	1.6635**	1.7370	1.7011*	1.6204**	1.6044*

^{a}*Note:* (***) significant at 1% level; (**) significant at 5% level; (*) significant at 10% level.

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