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Systemically important banks - emerging risk and policy responses: An agent-based investigation

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Systemically important banks - emerging risk and policy responses: An agent-based investigation

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Abstract

We develop a macroeconomic agent-based model to study the role of systemically important banks (SIBs) in financial stability and the effectiveness of capital surcharges on SIBs as a risk management tool. The model is populated by heterogeneous firms, consumers, and banks interacting locally in different markets. In particular, banks provide credit to firms according to Basel 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. Our model endogenously generates banks with different balance sheet sizes, making some systemically important. The additional capital surcharges for SIBs prove to have a marginal effect on preventing the crisis since it points mainly to the "too-big-to-fail" problem with minimal importance for "too-interconnected-to-fail", "too-many-to-fail" and other issues. Moreover, we found that additional capital surcharges on SIBs do not account for the type and management strategy of the bank, leading to the "one-size-fits-all" problem. Finally, we found that additional loss-absorbing capacity needs to be increased to ensure total coverage of losses for failed SIBs.

Keywords: financial instability; monetary policy; macro-prudential policy; systemically important banks, additional loss-absorbing capacity, Basel III regulation; agent-based models.

JEL classification numbers: C63, E52, E6, G01, G21, G28.

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1 Introduction

The Global Financial Crisis of 2007-2009 highlighted the role of global systemically important banks in transmitting financial shocks across countries and markets, having severe negative consequences for the real economy (Buch and Neugebauer, 2011; Balluck, 2015). Given their size, complexity, and systemic interconnectedness, distress or the disorderly resolution of these financial institutions has caused significant disruptions in the broader financial system and economic activity and has sometimes required public sector bailouts (see Freixas and Rochet, 2013; Ueda and di Mauro, 2013; Bongini et al., 2015; Mare et al., 2023, among others). Based on this knowledge, after the outbreak of the financial crisis, policymakers tried to identify which banks are essential to the stability of the global financial system and the main characteristics associated with systemically important banks (SIBs). Starting in 2011, the Financial Stability Board (FSB) has maintained a list of global systemically important banks, as part of an integrated set of policy measures to address systemic and moral hazard risks associated with systemically important financial institutions (SIFIs). The measures selected to identify and address SIFIs, following a long tradition, were size-based thresholds. This choice was mainly justified by transparency and easy implementation of those metrics. So was the road chosen by the Basel Committee on Banking Supervision (BCBS) publishing a document with a description of the methodology to select which Globally Systemically Important Banks (G-SIBs) should have additional capital requirements according to the Basel III agreement (see BIS, 2013). According to the methodology proposed, banks with a score produced by the indicator-based measurement approach that exceeds a cut-off level set by the committee are constrained to hold an elevated capital buffer. Along with addressing systemic and moral hazard risks connected to SIBs, additional capital surcharges strive to (1) constrain the ability of financial institutions to become systemically important by restricting their size, structure, or scope of activities; (2) lower the probability of bank failures through enhanced regulatory and supervisory requirements that go beyond the Basel III minimum capital standards; and (3) reduce the cost of their failures by enhancing their resolvability.

Ever since the academic literature is flourishing with an analysis of the effectiveness of the "indicator-based measurement approach" (IBMA, hereafter) proposed by BCBS to identify the systemic risks coming from these financial "giants" and offer alternatives (see Drehmann and Tarashev, 2013; Benoit, 2014; Moenninghoff et al., 2015; Poledna et al., 2017; Rovira Kaltwasser and Spelta, 2019; Poledna et al., 2021, among others). Recently, a spectrum of literature raised criticism against the methodology and measures implemented for SIBs, frequently suggesting that SIBs manage to surpass the regulation by lowering the capital surcharges (Berry et al., 2020) and in general, the "one-size-fits-all" approach offered by the BCBS is very limiting and focuses only on the problem of "too-big-to-fail" (Suh, 2019). Moreover, as suggested by Passmore and von Hafften (2019) the Basel III capital surcharge framework underestimates the probability of bank failure and excludes too many banks. Ultimately, the runs on Silicon Valley Bank and Credit Suisse in March 2023 restored attention to banking and financial regulation, resolution, and government intervention, pointing to the weaknesses in regulatory requirements and limited capacity to address such aspects as “too-big-to-manage” and “too-big-to-resolve”(see Admati et al., 2023; Danielsson and Goodhart, 2023).

Motivated by such considerations, in this paper, we develop a macroeconomic agent-based model to study how financial instability can emerge from SIBs and examine the SIBs as a crucial element in understanding the transmission and evolution of financial stress. For instance, one should better study how accurate the IBMA is in identifying the complex nature of banks and accordingly forcing them to a higher minimum capital standard. In this, we seek an answer to the following questions: How efficient is the BCBS method of identifying and neutralizing the SIBs in taming financial instability? Are additional capital surcharges enough to preserve the safety and soundness of SIBs? Is the additional loss-absorbing capacity for SIBs enough to overcome the “too-big-to-fail” problem and ensure that banks can cover their losses themselves? How do the regulations on SIBs interact with monetary policy?

We address these questions by extending the agent-based model developed in Popoyan et al. (2017, 2020) to include behavioral rules that will be characterizing the systemically important banks (i.e., dynamics bank-client network and relationship lending). Next, we apply the IBMA for the identification of SIBs and consecutively levy a higher regulatory burden that is supposed to, on the one hand, ensure adequate capital buffer in case of a bank’s failure, on the other hand, “neutralize” the financial “giant” in the network via restrictions on the reserve of exposures and limiting the contagion effect.[1]

The model describes an economy composed of heterogeneous firms, banks, consumers, the 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 Basel III. Finally, the Government performs fiscal policy, bails out banks in case of a crisis, and eventually issues bonds to finance the deficit.

We contribute to expanding the growing literature of agent-based macro-models integrating credit markets by analyzing the effects of interactions between macro-prudential regulation and monetary policy in a framework characterized by heterogeneous banks and firms. Some recent contributions in agent-based models address the question of financial stability connected to SIBs incorporating prudential instruments (see Klimek et al., 2015; Poledna et al., 2017; Teply and Klinger, 2019; Gurgone and Iori, 2021, among others). However, most of those contributions are based on credit network analysis with little consideration of the real side of the economy and the impact of monetary policy on financial “giants” and their risk-taking profile when higher capital requirements are imposed.

Our macroeconomic agent-based model is solved via 150 Monte Carlo simulations. Simulation

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

results show that the model endogenously generates SIBs considering the dynamic change of banks' size. As a result, starting from a symmetric setup (i.e., all the banks have nearly the same size), bigger and smaller banks appear along the simulations. Applying IBMA akin to Basel III accord we first identify and later apply additional capital requirements to SIBs. The additional capital surcharges proved to have a marginal and even negative effect on preventing the crisis. This performance is due to IBMA that is pointing mainly to the "too-big-to-fail" problem with minimal importance for "too-interconnected-to-fail", "too-many-to-fail", and other issues. Moreover, we found that additional capital surcharges on SIBs do not account for the type of bank, leading to the "one-size-fits-all" problem. Finally, we found that the capital buffer created, thanks to additional loss-absorbing capacity (ALAC), is insufficient to ensure total coverage of losses in failure SIBs.

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 is grounded on Popoyan et al. (2017) and Popoyan et al. (2020) and represents a self-organizing network of firms (i.e., shops), banks, and consumers/workers coordinating trading and production activities through mechanisms of exchange. Accordingly, our economy is populated by N agents, which can be consumers/workers (indicated by subscript z) or shops (denoted by subscript i), and by M banks (denoted by subscript m). The policy side of the model is facilitated by the Government managing fiscal policy and a Central Bank that sets monetary and macro-prudential policies. In the model, n different types of labor can produce n different types of non-perishable goods. Each agent is characterized by a pair (i, j), where i represents the agent's production good, and j and $j+1$ stand for the agent's primary and secondary consumption goods, respectively.[2] As there is one agent for every single type of good, the number of agents in the economy is equal to $N = n(n-2)$ and parameter n is responsible for the scale of the model. Since each agent is endowed with one unit of labor i and cannot consume the good it can produce (i.e., $i \neq j$ and $i \neq j+1$), they trade in goods and labor markets. Shops combine both production and trading activities (see also Howitt and Clower, 2000), financing production first with their stock of liquid assets and then(if necessary) with credit lines provided by banks. Loans to shops are made with full recourse and are collateralized by inventories. Banks accept deposits and grant credit lines to their clients following internal creditworthiness requirements and external macro-prudential regulations. The liquidity needs of the banking sector are satisfied in the interbank market, and if this option is exhausted, the bank can turn to the Central Bank.

[2] The primary and secondary consumption goods assumption is borrowed from Ashraf et al. (2011, 2017). This ensures that people trade with only a small fraction of all shops, capturing the localized nature of many real trading networks.

2.1 The timeline of events

At the beginning of the simulation, each agent in the economy is assigned a production good and primary and secondary consumption goods. Shops chose their production plans, relying on the distribution of types of goods in the economy. Along the simulation, the real and financial sides of the economy evolve, giving rise to multiple, non-linear feedbacks. Agents interact over a finite time horizon, indexed by $t = 1, ..., T$. Each period corresponds to a week, meaning that a month comprises 4 weeks, and a year comprises 48 weeks. 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;
5. trading in labor and good markets occur;
6. trading in financial;
7. bankrupted shops exit, and failed 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

Agent not owning a shop or a bank can decide to become an entrepreneur with probability θ/N ($1 \leqslant \theta \leqslant N$), representing the propensity to become an entrepreneur. A potential entrepreneur would enter the market only if the entry is profitable after paying the setup cost of S. If the profitability test is successful, the entrepreneur engages in a market search to find a prospective customer and a worker who would like to form an employment relationship with the new shop (see Appendix A for more details). The population of shops in the economy evolves over time, given the entry and exit process.

Trading in the labor market starts with shops fixing the normal wage w (see Eq. 17 in Appendix A.1) that can be updated consecutively (see Eq. 21 in Appendix A.3). A shop confirms its workers unless its labor input exceeds its target, and the ratio of the inventory-to-sales target (IS) exceeds the critical threshold. In its turn, a prospective worker will form an employment relationship with a new shop if the offered wage by the shop owner is more than her effective wage (w_t^{eff}). A worker (either employed or unemployed) can also search for a new job with probability σ ($0 \leq \sigma \leq 1$).

Similarly to the labor market, trading in the goods market starts with consumers observing the retail price (p_s) at the shops they are connected to and placing an order for a certain amount

(c_s) subject to their budget constraint (see Eq. 20 in Appendix A.2). If inventories of a shop are enough to fulfill the order, the consumer pays the price p_s^{eff}.[3] Agents can decide to switch the shop by asking for the retail price of a randomly chosen shop that produces the same consumption good the agent consumes. An agent will switch the shop if the price offered by the alternative shop is below the one he currently pays. By the end of searching and matching in goods and labor markets, agents adjust their balance sheets and fix their planned consumption expenditures.

2.3 Budget planning and portfolio choices

All agents in the economy (i.e., shop owners, consumers/workers, and bank owners), are planning their budget to smooth their consumption. As a first step, they adjust their permanent income ($Y^p_{z,t}$) from the previous period according to the following rule:

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

where Y_z, Y_z^p and λ_p are, respectively, the actual income, permanent income, and the adjustment speed parameter. Next, agents set their weekly planned consumption expenditure ($CE_{z,t}$) as a fixed fraction υ of their total wealth:

$$CE_{z,t} = \upsilon (A_{z,t} + Y^p_{z,t}), \tag{2}$$

where $A_{z,t}$ is the financial wealth and Y_z^p is the capitalized value of permanent income of the agent.[4] After planned consumption expenditure is set, agents decide how to reallocate the remaining wealth across financial assets (i.e., cash and deposit), with consumption needs facing a cash-in-advance constraint. It is worth mentioning that this choice differs depending on an agent type. The post-consumption wealth of workers is allocated to bank deposits. The saving strategy of a shop owner is similar to a worker's, except 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, credit and interbank network

The banking sector consists of M banks ($m = 1, ..., M$), that provide credit lines to shop owners to finance their production plans, and gather deposits. In period t, the balance sheet of bank m on the asset side consists of credit lines ($L^s_{m,t}$) defined as commercial loans extended to shop owners, measured as the value of principal and interest payable that week; seized collateral ($SC_{m,t}$), consisting of inventories and fixed capital seized by the bank from defaulting shops and valued at the

[3] More details about the workings and description of the goods market can be found in the Appendix A.3.

[4] 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 of the sum of the stock of cash and bank deposits less outstanding loans. For a bank owner, financial wealth is formed by cash in the bank's account plus the value of equity minus the amount of regulatory capital.

firesale price $P_{f,t}$; Government bonds($B_{m,t}$); interbank lending to other banks ($IB^b_{m,t}$) and Central Bank reserves ($R_{m,t}$). Bank m's liabilities consist of household deposits ($D_{m,t}$); borrowing from other banks ($IB^l_{m,t}$) and loans from the Central Bank ($L^{cb}_{m,t}$). For consistency, the main balance sheet identities hold in the model (see also Table 5) and the value of the bank's equity, $E^b_{m,t}$, is equal to the value of the bank's assets minus liabilities.

Banks first provide credit to firms. Then, they exchange reserves in the interbank market. Finally, they invest their residual reserves in Government bonds, which pay an interest rate and are reimbursed at the end of the period. Let us first consider how banks provide loans to firms. Banks receive credit line applications from their shops, and before confirming it, it passes a two-step procedure. First, banks check if granting credit would impede them from complying with the minimum capital requirement. Banks satisfying the minimum regulatory capital requirements (cf. Section 2.5) can provide credit to shops and set their supply according to a reserve of exposures constraint:

$$L^{sup}_{m,t} = \frac{1}{\overline{\epsilon_3}} E^b_{m,t} - (\psi_L L^s_{m,t} + \psi_{SC} SC^b_{m,t} + \psi_{IB} IB^b_{m,t}), \tag{3}$$

where $\overline{\epsilon_3}$ is the minimum capital requirement in the Basel III scenario. Notice that $(\psi_L L^s_{m,t} + \psi_{SC} SC^b_{m,t} + \psi_{IB} IB^b_{m,t})$ represents the bank's total exposure to credit risk (see Section 2.5 on the farther elaboration of bank's exposers to risk) where ψ_L, ψ_{SC} and ψ_{IB} are corresponding risk weights for loans (L), seized collateral (SC) and Interbank Loans (IB) in line with the values conformed by Basel III Standardised measurement approach (BCBS, 2016).

In the second step, after checking if a new loan can be covered by the exposure reserves described above, the bank will either approve or deny the request, depending on the borrower's creditworthiness (see Eq. 4, 5, 6 and 7 below) and the size of the collateral provided. In particular, bank grant credit based on a "6C" approach of creditworthiness (Popoyan et al., 2017, 2020) that is commonly used in practice to identify the financial vulnerability of the potential clients (see, e.g. Jiang, 2007; Das, 2014). Note that we have adapted the approach to the indicators we are able to compute, restricting it to only Capital, Capacity, and Collateral since the remaining three C's (i.e., Conditions, Character, and Common sense) are subjective and based on the credit grantor's historical experience with their clients. 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):

$$QR_{i,t} = \frac{\text{Current Assets-Inventories}}{\text{Current Liabilities}} = \frac{D^s_{i,t} + H^s_{i,t} - I_{i,t}}{L^s_{i,t}} \geq \kappa, \tag{4}$$

$$ROA_{i,t} = \frac{\text{Net income(after tax)}}{\text{Total assets}} = \frac{\Pi^s_{i,t}}{D^s_{i,t} + H^s_{i,t} + I_{i,t}} \geq \zeta, \tag{5}$$

where H^s_i, D^s_i and $I_{i,}$ are respectively cash and deposits and the value of inventories of the shop i, $\Pi^s_{i,}$ are its profits, and $0 < \kappa < 1$ and $0 < \psi < 1$ are parameters. Their values are set on the ground of real-world practices of banks (see e.g., Das, 2014).

The *Capital* check is performed by using the "debt-to-equity" ratio (DER):

$$DER_{i,t} = \frac{\text{Total liabilities}}{\text{Equity}} = \frac{L^s_{i,t}}{E^s_{i,t}} \geq \varrho, \tag{6}$$

with $0 < \varrho < 1$.

Finally, firms satisfying the three conditions above undergo the *Collateral* check. The loans are fully collateralized by fixed capital and inventories of shops. The price of collateral is set by applying a constant loan-to-value ratio h ($0 < h < 1$) to the unit value of inventories, assumed to be equal to their marginal cost of production ($W_t(1 + \pi^*)$):

$$P_{h,t} = hW_t(1 + \pi^*), \tag{7}$$

where h is a constant loan-to-value ratio, W_t is the publicly known average wage rate across all shops computed by the Government, and π^* is the Central Bank'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. Accordingly, the shop owner can borrow up to his credit limit set equal to the haircut value of his eligible collateral to which the bank applies a haircut price P_h (see Eq. 7).

If either for a little reserve of exposure or because of incompliance with one or more indicators of creditworthiness, the bank can reject the loan application, the client can apply to other banks with more exposure reserves and better lending conditions (e.g., lower interest rate). It is worth noticing that if a shop's credit demand is higher than the bank's residual credit supply (see Eq. 3 above), the shop is credit rationed (Stiglitz and Weiss, 1981). Moreover, the dynamics Bank-Client network, missing in Popoyan et al. (2017, 2020), is a crucial property in the emergence of systemically important banks together with relationship lending, which supposes the Bank-Bank and Client-Bank links are persistent through time - you prefer to borrow from the banks you used to, the bank prefers to lend a client that never let him down (Presbitero and Zazzaro, 2011; Sette and Gobbi, 2015; López-Espinosa et al., 2017).

In this version of the model, the bank's lending rate is heterogeneous across banks. Banks fix such a rate by applying an annual spread ($s > 0$) on the nominal interest rate set by the Central Bank (see Eq. 12)[5] and according to a component Ω that is a decreasing function of reserve of exposures ($L^{sup}_{m,t}$):

$$i^L_t = i_t + s/48 + \Omega_t. \tag{8}$$

[5]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.

Finally, the deposit interest rate equals the Central Bank interest rate, i.e., $i_t^D = i_t$.

Banks can also lend to other banks and borrow from them before turning to the Central Bank to manage their liquidity. Demand and supply of liquidity arising from liquidity requirements 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 details on matching the supply and demand for liquidity is in Appendix A.7). If the bank's high-quality liquid assets fall short of expected net cash outflows, the bank will demand liquidity, otherwise, it will supply funds in the interbank market. 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 m bank's balance sheet. If a bank misses enough collateral to meet its residual liquidity demand, then it cannot fulfill the liquidity coverage ratio. Under Basel III, this implies that the bank will be considered "troubled" and, therefore, able to supply credit once the requirement is fulfilled again.

The Central Bank charges an interest rate to the bank higher than the one in the interbank market to assure that banks seek money first in the open interbank market before turning to the CB's standing facilities. The interbank rate instead, determined in detail in Appendix A.7 is defined inside the corridor window and depends on the policy rate (i_t), on the current financial soundness of bank ($\varepsilon_{i,t}$) and the current supply of excess liquidity reserves (Θ). The logic behind the interbank rate formation is in line with Whitesell (2006). It shows that if the supply of excess liquidity reserves is close to 0, the interbank rate would be more comparable to a policy rate. At the same time, when the supply of liquidity is more than the demand, the interbank rate would fall below the policy rate and increase above the policy rate if the demand is higher than the supply of liquidity (see Eq. 27 in Appendix A.7).

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

$$P_{f,t} = \frac{W_t(1 + \pi^*)}{2}. \tag{9}$$

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. Bankrupt banks, if previously identified as systemically important (see Section 2.6), are using their total loss-absorbing capacity buffer and, if not enough, are bailed out by the Government, which injects enough sources until the equity satisfies the minimum regulatory requirements (see Section 2.5 below).

2.5 Fiscal, monetary and macro-prudential policies

In this section, we describe the policy framework of the model. The policy wing includes the Government levying a sale tax to service the interest on its debt, issued as bonds, and recapitalizing failed banks. At the same time, a Central Bank sets the monetary policy via interest rate and the associated interbank corridor, lends to banks, and sets the macro-prudential rules banks must comply with.

Fiscal policy. The Government runs the fiscal policy by gathering a sales tax τ from each transaction in the goods market. Collected tax revenues are directed to bail out failed banks and to service government debt. If the expenditure for bailouts exceeds tax revenues, the Government issues new bonds that last one period. The Government pegs the interest rate on those bonds equal to the Central Bank's policy rate i, by buying and selling whatever quantity the banks wish to hold at that rate. Banks buy government bonds with their residual reserves. Eventually, the Central Bank buys the residual quantity of the issued bonds. The tax rate is adjusted once per year, considering the dynamics of the debt-to-GDP ratio (see Appendix A.4, Eq. 23 for more details).

Monetary policy. The Central Bank conducted the monetary policy by setting the nominal interest rate i by using a "classical" Taylor rule (Taylor, 1993; Howitt, 1992) in the baseline scenario and a double-mandate and three-mandate "leaning-against-the-wind" Taylor rule in alternative ones, and revising it every month (4 weeks). Accordingly, the nominal interest rate in the baseline scenario is computed as "classical" Taylor rule ($TR_{\pi,y}$) and reads as follows:

$$ln(1+i_t) = max\{ln(1+i_t^*) + \varphi_\pi(ln(1+\pi_t) - ln(1+\pi^*)) + \varphi_y((y_t - y_t^*), 0\}, \tag{10}$$

where π^* is the fixed inflation target, $(1+\pi_t)$ is the inflation in the past 12 months, φ_π and φ_y are fixed coefficients ($\varphi_\pi > 1$ and $0 < \varphi_y < 1$), 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.

As an alternative monetary policy scenario a three-mandate "leaning-against-the-wind" Taylor rule is considered ($TR_{\pi,y,c}$), which also takes into account credit dynamics:

$$ln(1+i_t) = max\{ln(1+i_t^*) + \varphi_\pi(ln(1+\pi_t) - ln(1+\pi^*)) + \varphi_y(y_t - y_t^*) + ln(\frac{C_t}{C_{t-1}})^{\varphi_c}, 0\}, \tag{11}$$

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., 2017; Lambertini et al., 2013).

The third scenario of monetary policy evolves around the "dual-mandate" Taylor rule. In this case, Central Bank responds to inflation and unemployment dynamics (TR_{π}, u):

$$ln(1+i_t) = max\{ln(1+i_t^*) + \varphi_\pi(ln(1+\pi_t) - ln(1+\pi^*)) + \varphi_u((U_t - U_t^*), 0\}, \tag{12}$$

with $\varphi_\pi > 1$ and $0 \leq \varphi_u \leq 1$. and U^* is the target unemployment rate (Dosi et al., 2015).

In addition to defining the nominal interest rate, the Central bank also manages the corridor for its lending/deposit facility to banks, thus influencing the interest rate fluctuations in interbank (see Appendix A.7 for detailed description). This intervention is made by setting the $\phi_l > 0$ and $\phi_d > 0$ parameters (cf. Equation 27) that define the corridor width (for details, refer to Appendix A.7). For the sake of simplicity, in this setup, we fix the corridor widow parameters and don't adjust them as done in Popoyan et al. (2020).

Macro-prudential policy. Central Bank also controls the regulatory compliance of bank activities through macro-prudential policies. In this model, we have incorporated all the post-crisis Basel III accord levers, adding to the Popoyan et al. (2020) the missing one - the additional capital surcharges on the SIBs. Our main goal 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. In particular, we are interested in the emergence of systemic banks, their identification, and the impact of the additional capital surcharges on the financial stability and broader economy. In this, we describe the components of the Basel III regulatory setup.

The *Basel III* macro-prudential framework aims at reducing systemic risk originating from financial institutions by reinforcing the capital requirements and inserting global liquidity requirements. The former focuses on creating a capital cushion for bad times, limiting excess leverage, identifying systemic banks, and implementing higher capital requirements for financial "giants".

The global capital requirement part is based on three constraints that banks must comply with 1) the static minimum capital requirement ($CAR^3_{m,t}$), 2) the counter-cyclical capital buffer on top of the latter ($CCB_{m,t}$), 3) additional loss-absorbing capacity ($ALAC^{SIB}_{m,t}$) for SIBs, and 4) the leverage ratio ($LR_{m,t}$).

1. The *static minimum capital requirement (CAR3)* under Basel III setup improves on the minimum capital standard of pre-crisis Basel II 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:

$$CAR^3_{m,t} = \frac{Tier1_{m,t}}{RWA_{m,t}} = \frac{E(T1)^b_{m,t}}{\psi_{IB} IB_{m,t} + \psi_L L^s_{m,t} + \psi_{SC} SC_{m,t}} \geq \overline{\epsilon_3}, \tag{13}$$

where $\overline{\epsilon_3} = 4.5\%$.[6]

[6] The values of the parameters $\psi_{IB} = 0,2; \psi_L = 1; \psi_{SC} = 1$ are in line with the standardized approach to credit

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;[7] (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 the credit-to-GDP gap until the latter reaches the ceiling H.[8] Then it remains constant at the upper bound of 2.5%.

3. The *additional loss-absorbing capacity for SIBs ($ALAC^{SIB}_{m,t}$)* is added to the $CAR3 + CCB$ chasing two main objectives - ensure adequate capital buffer in case of bank's failure, and "neutralize" the financial "giant" in the network via restrictions on the reserve of exposures and limiting the contagion effect. The SIBs are identified by applying the indicator-based measurement approach proposed by the BCBS (BIS, 2013) according to which a core of systemic importance is assigned ($Score_{m,t}$). The details about the identification of SIBs can be found in Section 2.6. If the bank is identified to be systemically important ($1 \leq Score_{m,t} \leq 5$), the bank is placed in one of the buckets below [9], and the bank's capital requirement includes an additional capital surcharge for SIBs.

Bucket	*Minimum additional loss absorbency (Tier 1 equity as a percentage of risk-weighted assets)*
5	3.5%
4	2.5%
3	2.0%
2	1.5%
1	1.0%

Table 1: Bucketing approach and Additional loss-absorbing capacity (ALAC)

risk measurement for capital requirements in the Basel III framework (see BIS, 2019).

[7] 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 a yearly bases.

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

[9] Note that we calibrate the buckets fully respecting the bucketing approach and measure published from 2011 each year by the financial stability board (FSB). For details, see `https://www.fsb.org/work-of-the-fsb/market-and-institutional-resilience/global-systemically-important-financial-institutions-g-sifis/`.

4. 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):

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

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

The global liquidity requirement is achieved in the Basel III framework via the *liquidity coverage ratio (LCR)* (see Appendix A.7, cf. Eq. 24). 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.[10]

2.6 SIB's, their identification and regulation

The literature knows several ways of measuring systemic importance. They fall into two main categories: dynamic and static. The dynamic approach is based on statistical modeling of the losses of the system as a whole and their subsequent allocation to its individual components to determine the most significant contributor to systemic risk (Tarashev et al., 2010; Yang et al., 2020; Su and Xu, 2021). The static approach uses static quantitative and qualitative indicators that allow for simple comparison and further analysis of the system's individual components. Due to its flexibility, simplicity, and transparency, the static approach seems more practical for micro-prudential and macro-prudential policy-making. In fact, it has been used to identify global systemically important banks by BCBS and consequently became a part of the post-crisis Basel III regulatory setup (BIS, 2013).

For the sake of our analysis, we have adjusted the BIS (2013) methodology to define the systemically relevant banking institutions employing precisely the same technique. The comparison and difference between the BIS methodology and our adaptation can be found in Table 2. The only substantial difference lies in a different choice of one of the financial indicators, which are used to reflect the five categories of systemic relevance. The categories are chosen to emphasize the different aspects that generate negative externalities and make a bank critical for the financial system's stability: size, interconnectedness, substitutability, complexity, and sentiments. The *size* of banks can be regarded as the key measure of systemic risk. The larger a bank is, the higher the potential damage that arises from its failure. A common and observable proxy to reflect the total activities of a bank can be found in the "total assets" of its balance sheet ($TotalAssets_{m,t}$). The *interconnectedness* of banks can create substantial risks that threaten the financial system's

[10]Basel III also distinguishes between different types of high-quality assets that enter into 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.

stability since the troubled institution, not being able to repay its interbank debt, increases the likelihood of distress for other financial institutions. Hence, the systemic impact of a bank greatly depends on its degree of interconnection (Allen and Gale, 2000). Considering the simplicity of our balance sheet, we focus on interbank transactions only. The respective items include loans to banks (IB^l_m) and deposits from other banks (IB^a_m). *Substitutability* reflects the importance of a bank as a service provider. According to the Basel Committee, the systemic importance of banks should be negatively related to the substitutability of their services. If the banks are systemically important, alternative suppliers' substitutions must be considered unrealistic. To measure substitutability, we use easily observable indicators to picture economic sectors' dependency on bank capital, i.e., the credit to firms (L^s_m) and government bonds (B^b_m). The following official categories tend to account for the "too-complex-to-fail" theory. BCBS argues that the systemic risk following a bank's failure is likely greater the more complex its business, structure, and operations are. This category comprises the investment securities (B^b_m) and Level 3 assets (SC_m). As the last category, BCBS includes the "cross-jurisdictional activity". Since the model lucks "the rest of the world", we replace it with the proxy to emphasize an institution's domestic relevance. By choosing the domestic sentiments relying on the deposits banks hold (D_m), we capture the public perception of the domestic impact that is caused by a bank's failure.

Category (weighting)	***BCBS approach (G-SIB)***	***Adjusted BCBS approach (D-SIB)***
Size	Total exposures as defined for use in the Basel III leverage ratio	Total assets (100%)
Interconnectedness	Intra-financial system assets Intra-financial system liabilities Wholesale funding ratio	Loans to banks (50%) Deposits from banks (50%)
Substitutability	Assets under custody Payments cleared and settled through payment systems Values of underwritten transactions in debt and equity markets	Loans to firms (50%) Loans to government (50%)
Complexity	OTC derivatives notional value Level 3 assets Held for trading and available for sale	Investment securities (50%) Level 3 assets (50%)
Cross-jurisdictional activity	Cross-jurisdictional claims Cross-jurisdictional liabilities	*not included*
Sentiments	*not included*	Deposits from households (100%)

Table 2: Indicators of official and adjusted approach of SIB identification

The proposed methodology gives equal weight to each of the five categories of systemic importance, which are weighted inside the group. Each group is normalized to 1. For each bank, the score for a particular indicator is calculated by dividing the individual bank amount by the aggregate amount summed across all banks in the sample for a given indicator. The score is then weighted by the indicator weighting within each category. Then, all the weighted scores are added. The maximum possible total score is 5. The procedure is described in Eq. 14.

$$Score_{m,t} = \underbrace{\frac{TotalAsset_{m,t}}{\sum_{m=1}^{25} TotalAsset_{m,t}}}_{\text{Size}} + \underbrace{0.5\Big(\frac{IB^{l}_{m,t}}{\sum_{m=1}^{25} IB^{l}_{m,t}} + \frac{IB^{a}_{m,t}}{\sum_{m=1}^{25} IB^{a}_{m,t}}\Big)}_{\text{Interconnectedness}} + \tag{14}$$

$$\underbrace{0.5\Big(\frac{B_{m,t}}{\sum_{m,t}^{25} B_{m,t}} + \frac{L^{s}_{m,t}}{\sum_{m,t}^{25} L^{s}_{m,t}}\Big)}_{\text{Substitutability}} + \underbrace{0.5\Big(\frac{SC_{m,t}}{\sum_{m,t}^{25} SC_{m,t}} + \frac{B_{m,t}}{\sum_{m,t}^{25} B_{m,t}}\Big)}_{\text{Complexity}} + \underbrace{\frac{D_{m,t}}{\sum_{m,t}^{25} D_{m,t}}}_{\text{Sentiments}}$$

Having individual scores, we will group SIBs into different categories of systemic importance based on the score produced by the indicator-based measurement approach. SIBs will be allocated into five buckets based on their systemic importance scores, with varying levels of additional loss absorbency requirements applied to the different buckets. The relative buckets the banks are placed in can be found in Table 1. Each bucket would be required to hold an extra level of additional common equity ranging from 1% to 3.5% of total risk-weighted assets on top of the minimum capital requirement.

3 Simulation results and policy experiments

As is typically the case for agent-based models (ABMs), our model does not allow for analytical and closed-form solutions (see Fagiolo and Roventini, 2017, for detailed discussion), considering the high-dimensionality of the dynamical system. Accordingly, we perform Monte Carlo simulations to explore stochastic processes driving the model's co-evolution of micro and macro variables. We simulate the model with 150 independent runs, each comprising 60 years of simulation. The first ten years of the simulation until the model settles down, as is customary for ABMs, is treated as a transient. Therefore, all results are based on model outputs for 50 years (i.e., from year 11 onward). The values of the parameters of the model are introduced in Table 4 in Appendix B.

The calibration strategy of the model closely follows the one in Ashraf et al. (2011, 2017) and is conducted in 3 levels. At the first level, a subset of parameters is directly borrowed to match their empirical counterparts in the U.S. data and/or the values used in previous empirical studies. Among those parameters are $\varepsilon, \Delta, \beta, b^*, \kappa, \varrho, \zeta, s, \psi_L, \psi_{SC}, \psi_{IB}, \varphi_\pi, \varphi_y, \pi^*$. The second calibration level proceeds with selecting parameters' values to be internally consistent with median outcomes across simulations. Examples of such parameters are the initial value of real interest rate (r^*) and the initial value of potential output, $\bar{y}$. The third calibration level focuses on the residual parameters (i.e., ones not entering the first and second levels). Those parameters are calibrated indirectly to make the simulations' median outcomes match specific U.S. data properties (i.e., $S, I.S., \delta_p, \lambda_p, \sigma, \theta, \eta_r, h$). [11]

The model needs empirical validation before one can convincingly state that we can effectively analyze the policy questions concerning financial and economic stability, the efficiency and impact of post-crisis Basel III regulations imposed on SIBs, and interactions between macro-prudential

[11] For a discussion of empirical validation of agent-based models, see Fagiolo et al. (2017).

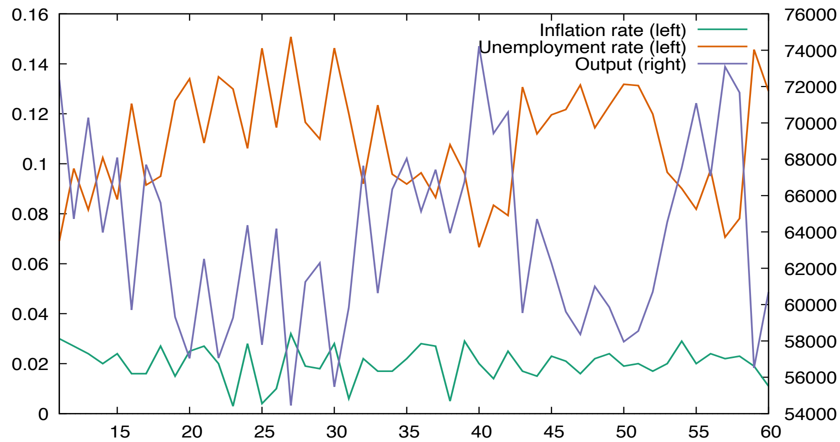


Figure 1: The time series of output, inflation, and unemployment (50 years).

and monetary policies. The model can replicate a wast list of macro and micro-stylized facts in the benchmark scenario, pointing to the model's capacity to capture the long-run and short-run behavior of the economy. As illustrated in Figure 1, the model exhibits endogenous business cycle fluctuations in terms of output, inflation, and unemployment rate.

Next, we investigate if our calibrated model can replicate the co-movement of different macroeconomic indicators with output over the business cycle, relying on the methodology offered by Stock and Watson (1999) and Napoletano et al. (2006). Accordingly, we compute the cross-correlation structure between the output and main macroeconomic variables (consumption, unemployment, credit, inflation, change in inventories, and others). As confirmed by the empirical evidence, the cross-correlation analysis of our simulated data demonstrates the pro-cyclical nature of consumption, inventories, inflation, and credit, as well as the counter-cyclical behavior of unemployment and prices. As its predecessor Popoyan et al. (2017, 2020), the model is able to reproduce Okun's law and the Phillips curve on the simulated data. The results are reported in Figure 3.

3.1 Emergence of SIBs

We solve the model via 150 Monte-Carlo simulations over 60 years. We first look at the size of the banks and their scores of systemic importance as a barometer of the emergence of SIBs. Such dynamic is presented in Figure 4. This bubble chart depicts the size of 25 banks present in the simulation at three different points in time - the beginning of the simulations (T=11), middle (T=45), and end (T=60). The diameter of the bubble indicates the size of the bank measured in therm of the size score described in Eq. 14. We initialize the banks' balance sheets to have all the banks start in a symmetric setup (i.e., having more or less the same size). As the figure speaks for itself, due to the dynamic bank-client network and the relationship lending, along the simulation time, we have banks that become more significant in the market and systemically more important.

Next, we look at the correlation matrix of the relations among the analyzed five categories of systemic importance (i.e., size, interconnectedness, complexity, substitutability and sentiments)

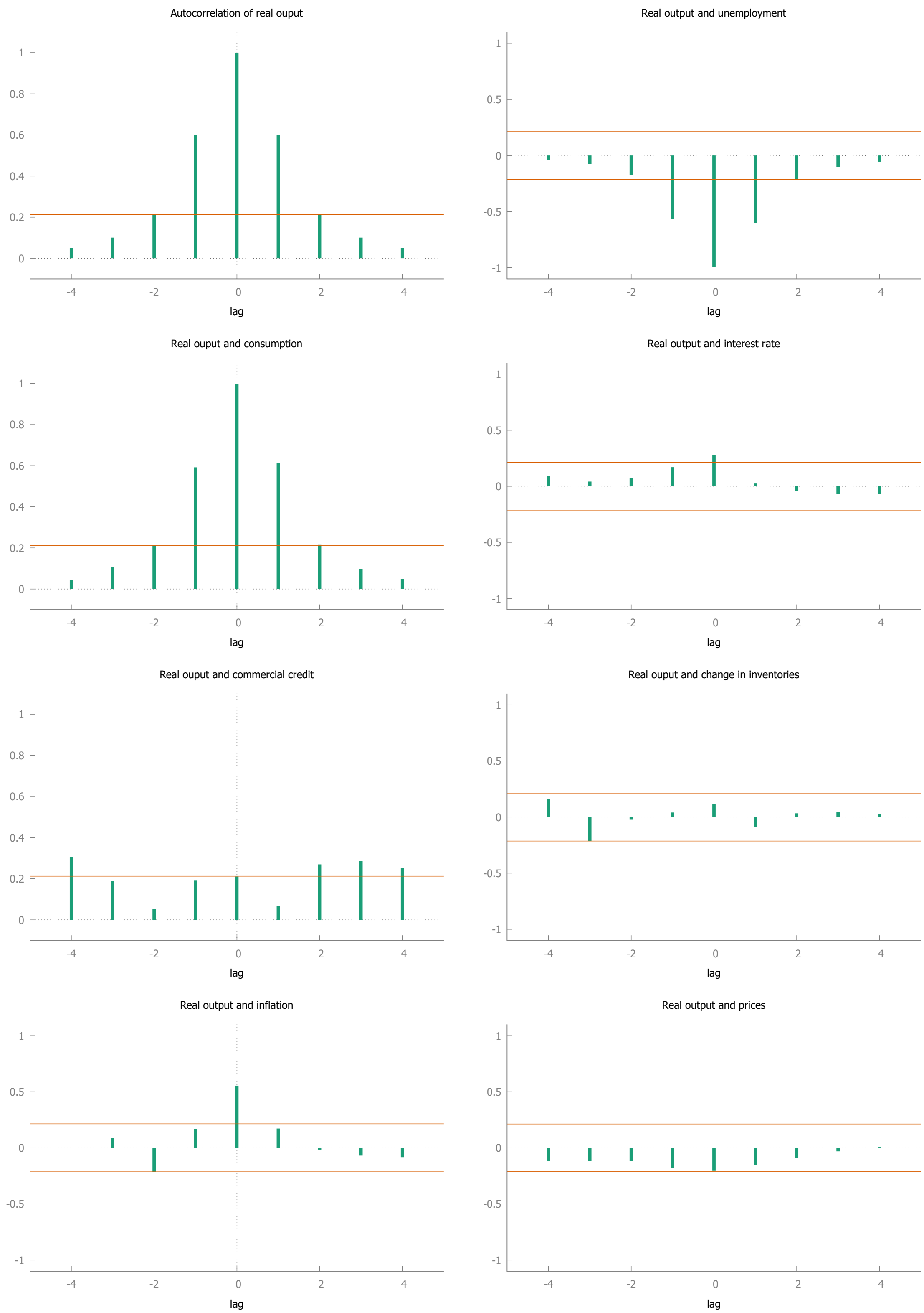


Figure 2: Cross-correlations between HP-filtered output and main macroeconomic aggregates.

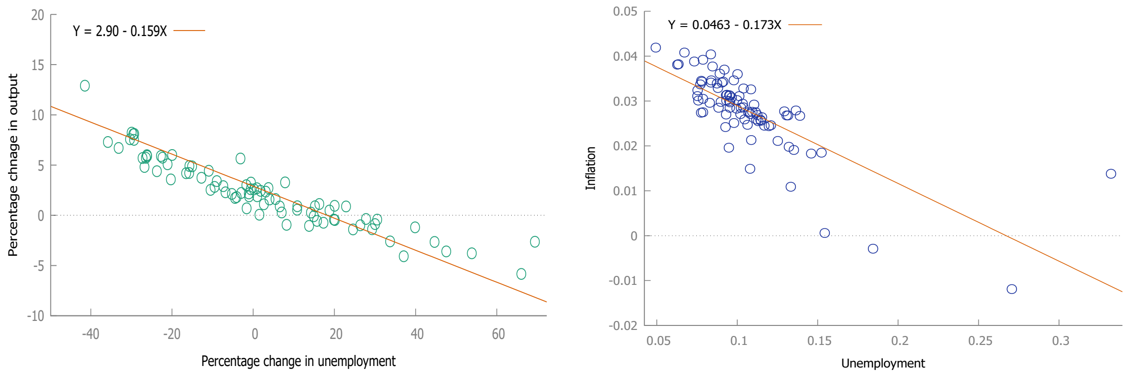


Figure 3: Okun's law (left) and Philips curve (right)
Note: Okun's law is presented as an OLS estimation of the relationship between the percentage change in output and the percentage change in unemployment with $R^2 = 0.42048$. Phillips curve is presented as an OLS estimation of the relation between inflation and unemployment with $R2 = 0.41314$. The H0: "the estimated coefficient is not significantly different from zero" is rejected at the 1%.

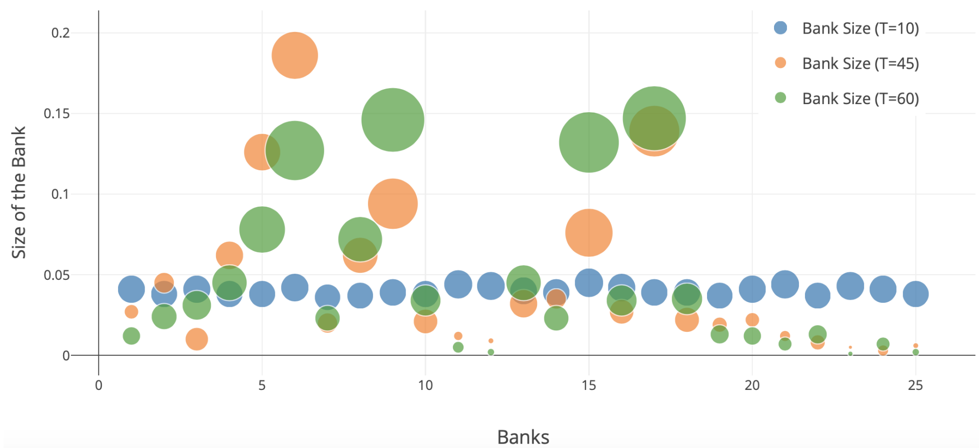


Figure 4: Emergence of SIB in defferent time spots of simulation

described in Section 2.6 considering two correlation matrices with corresponding heatmaps: (1) entier sample of banks vs. the first five SIBs and (2) entier sample of banks vs. sample without the SIBs. The results are illustrated in Figure 5 , featuring the above 2 cases. As the scores are not normally distributed, Spearman's coefficient of rank correlation was used for greater robustness and comparability of the two samples. Figure 5 first reveals that systemic importance cannot be entirely simplified to institution size. Moreover, it is evident from comparing the two heatmaps below that in the figure on the left (e.g., entire sample vs. 5 SIBs), the indicators for these five institutions are strongly correlated to the entire sample. Such strong correlations cannot be observed among less and medium important institutions in the heatmap on the right.

In further search for the properties of SIBs, we looked at the statistical distribution of 5 systemically important indicators. The results are shown in Figure 6 and reveal that the categories of

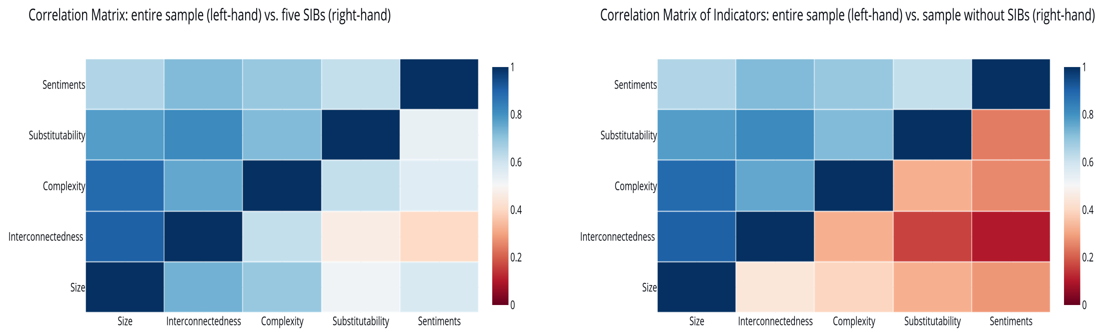


Figure 5: Correlations between SIB components: Spearman's coefficient of rank correlation between the scores

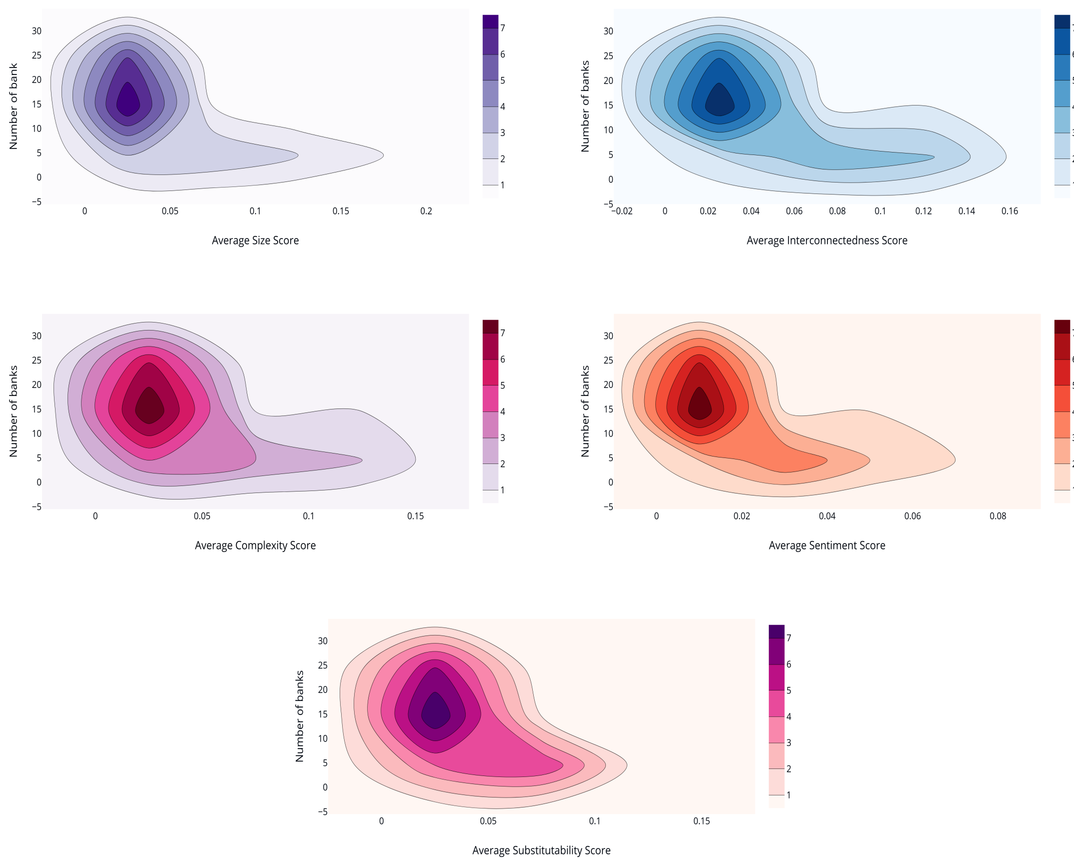


Figure 6: Estimated Distribution of Quantitative Indicators: Kernel density estimates for the scores

quantitative indicators all have relatively similar distributions. Accordingly, in each category separately, we find a large number of institutions that have normal importance in the given respect (the left-hand part of the chart) and a small number of institutions that can be described as important (the right-hand part of the chart). However, we can also notice that in terms of scale, the most significant indicator is size.

3.2 Macroeconomic and Financial Stability

In this section, we explore the possible interactions between monetary policy and two different macro-prudential policy setups on such target variables as the output gap, unemployment, inflation rate, and the likelihood of the economic crisis (defined as a drop of GDP higher than 3%). As possible monetary policy setups, we consider the "classical Taylor" rule ($TR_{\pi,y}$), "leaning against the wind" Taylor rule ($TR_{\pi,y,c}$) and "dual-mandate" Taylor rule ($TR_{\pi,u}$). The macro-prudential policies we consider are grouped into two main clusters: (1) full-fledged Basel III regulations, including the global capital requirements, the additional capital surcharges on SIBs, and the global liquidity standard and (2) Basel III setup from which additional loss-absorbing capacity (ALAC) for SIBs is excluded from the instrumental toolkit. The results of the policy experiments are reported in Table 3. Each entry in a table returns the ratio between the Monte Carlo average of the macroeconomic variables generated under a given prudential and monetary policy combination and the one in the benchmark scenario (i.e. Basel III and "Classical Taylor" rule).

	Output Gap	Unemployment	Inflation	Likelihood of Econ. Crisis
	"Classical Taylor" rule ($TR_{\pi,y}$)			
Basel III	1	1	1	1
	-	-	-	-
Basel III - ALAC	0.9334**	0.7471*	0.9346	0.8438**
	(0.1123)	(0.1204)	(0.0745)	(0.1677)
	"Leaning against the wind" Taylor rule ($TR_{\pi,y,c}$)			
Basel III	0.8954*	0.8249**	0.9311	0.7256*
	(0.0934)	(0.1156)	(0.0406)	(0.1798)
Basel III - ALAC	0.8465*	0.7644	0.9306*	0.7267
	(0.1034)	(0.1786)	(0.1023)	(0.1609)
	"Dual-mandate" Taylor rule ($TR_{\pi,u}$)			
Basel III	1.4576**	0.8032*	1.0165*	2.3245*
	(0.1432)	(0.2032)	(0.0965)	(0.2875)
Basel III - ALAC	1.4230*	0.8706	0.9432*	2.1206**
	(0.2367)	(0.1846)	(0.1206)	(0.2476)

Table 3: Economic performances under different monetary policy rules and macro-prudential tools.
Note: Absolute value of the simulation t-statistic of H0: "no difference between baseline and the experiment" in parentheses.
*Significant at 10% level.
**Significant at 5% level.

We start by comparing the performance of post-crisis Basel III, which includes the ALAC for systemic banks, and with a case when the requirement on the letter is missing. Introducing the ALAC to Basel III's main instruments has little to sometimes a destabilizing effect on macroeconomic performance. We can notice that having "Basel III - ALAC" would decrease the output gap, unemployment level, and the probability of an economic crisis. This scenario persists almost in all three monetary policy scenarios. Moreover, considering the different monetary policy scenarios, in line with Popoyan et al. (2017) and Popoyan et al. (2020), the "leaning against the wind" Taylor rule stabilizes the macroeconomy. We further analyze the average impact of additional loss-absorbing capacity on SIBs on the bank failure rate, one measure of financial stability. We do so using the violin plot in Figure 7 which combines a boxplot and kernel density plot. We discuss the case for three different monetary policy setups. We find that the higher capital requirement of SIBs has a marginal effect on the banks' failure rate, and if it shows some positive change, it happens under the "leaning against the wind" monetary policy rule.

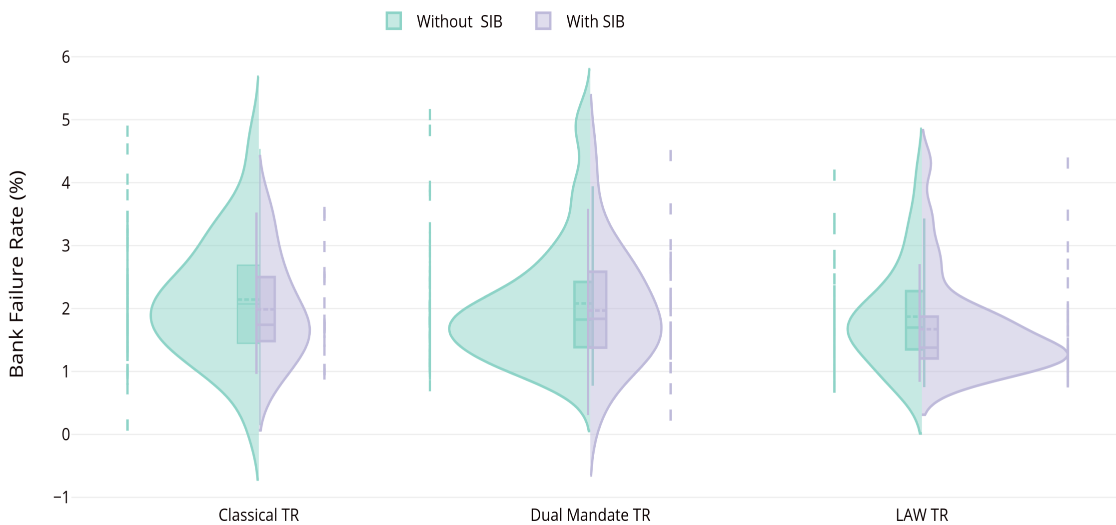
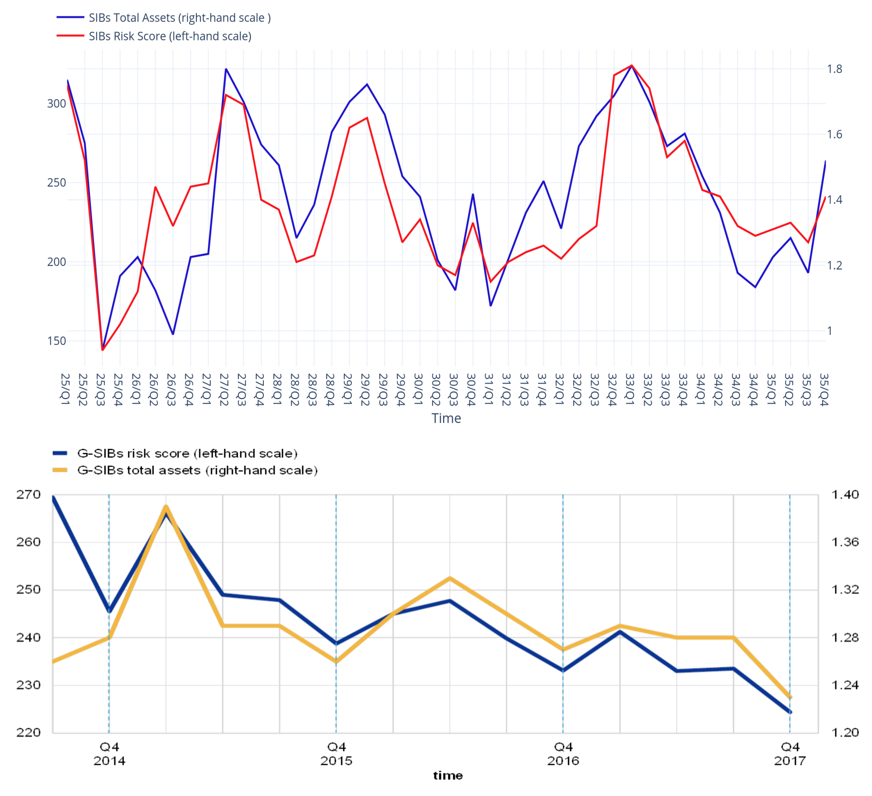


Figure 7: Violin plot of SIBs regulation effect on bank failure rate.

Searching for the answers to this marginal effect of SIB's capital buffer on financial stability, we found an interesting relation that appears to repeat in the real financial market. This relation is presented in Figure 8, where we trace the dynamics of total assets of SIBs (a measure of *size* component in indicator-based approach) and Risk score ($Score_{m,t}$) in simulated date (see Figure 8, top) and in actual data (see Figure 8, bottom). It highlights a robust positive correlation between the total assets of SIBs and their risk score in simulation and real data. Combining later dynamics with a correlation of Score indicators and distribution of quantitative indicators proves each component's contribution, showing that the driver of the SIBs score is mainly the *size* indicator. This, in turn, brings to a problem of a measure that orients on "one-size-fits-all". Adopting the concept of systemically importance akin to BCBS and relying mainly on the size of the intermediary is prone to overlooking and not accounting for the type and actual financial activities of the bank. We present two balance sheets in Figure 9 for a broad idea of the inherent problem. As one can see, the two balance sheets are the same in terms of size, but when we look at the composition of items, we notice that one is relying heavily on commercial loans while the second is on Government bonds. Accordingly, regarding risk profile, the first banks should be considered more risk-taking and hence more troublemaker if a failure occurs, while the second is not. The problem lies in the following aspect - the BIS method is looking at two cases with the same eye (i.e. "one-size-fits-all") without distinguishing between the actual activity of the banks, its business model, and the loss caused by the failure depending on their risk profile. This very much reminds the Silicon Valley Bank and Credit Suisse case in March 2023. Accordingly, the

BIS Identification procedure and regulation of SIBs mainly address the "too-big-to-fail" problem, overlooking "too-many-to-fail", "too-interconnected-to-fail", and others.



Source: ECB staff calculations based on FINREP and EBA data (Q3 2014 to Q4 2017).

Figure 8: Bank Size and SIB Score: Simulation vs. Reality

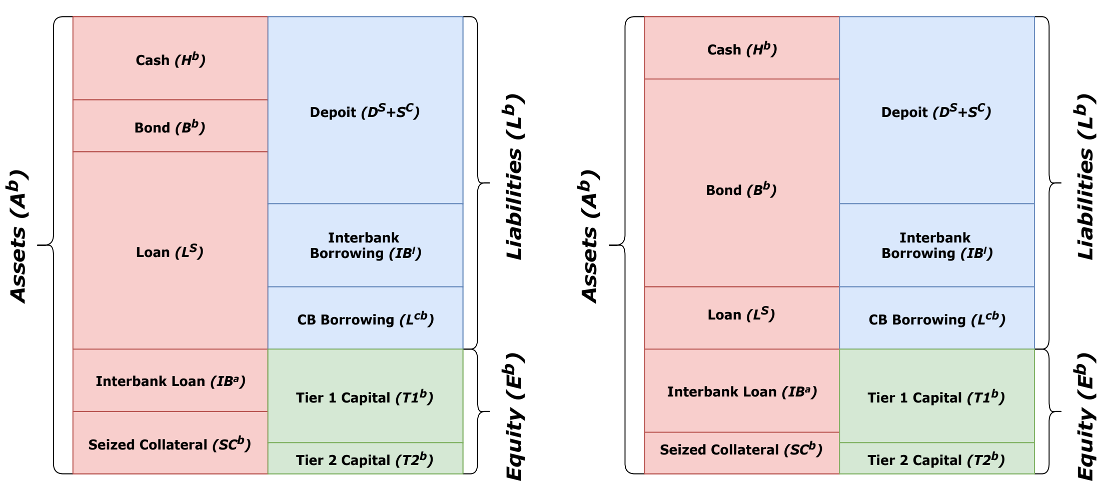


Figure 9: Balance sheets of two identical risk score banks

Having the insights obtained above, we evaluate the impact of capital requirements on SIBs on financial stability using the financial stability map proposed by Aikman et al. (2014). Figure 10 displays a radar plot of six components (i.e., size, leverage, maturity mismatch, concentration, GDP volatility and credit-to-GDP gap) underlying vulnerabilities of the financial system showing the impact of the different combinations of macro-prudential rules on several dimensions capturing the vulnerability of the banking sector in case if additional capital regulation is applied on SIBs (figure on the right) and in case if it is not used (on the left). Bank leverage is measured as bank assets to capital; maturity mismatch is loan-to-deposit ratio; the size of the financial sector is computed as the ratio between financial sector assets to GDP; concentration measure is the ratio between assets of the top 5 banks and assets of the whole financial system. The outer polygon represents the maximum value of each component over the sample, representing a highly vulnerable financial system; the central polygon represents the minimum, in which case the system would appear exceptionally resilient. We have normalized the data via normal cumulative distribution function (CDF) to place the measures on the (0,1) interval. As we can see in the figure, the additional capital surcharge on SIBs has a positive effect on the size, a marginal effect on leverage, and an adverse impact on the credit-to-GDP gap. Accordingly, the higher capital requirement on SIBs is reducing the size of financial institutions while decreasing credit availability, considering that the model functions with a strong financial accelerator mechanism on the supply side of credit.

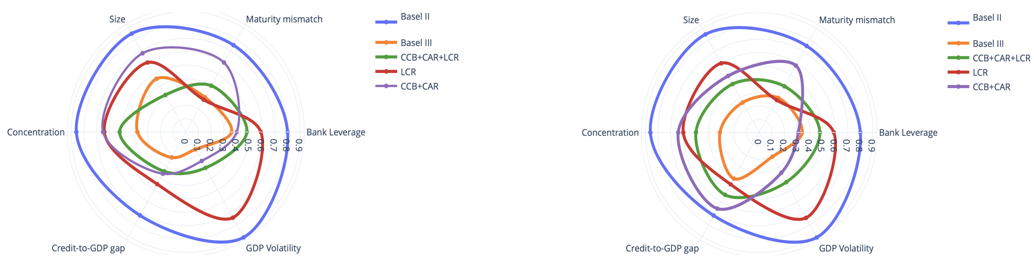


Figure 10: Financial Vulnerability Across Prudential Instruments in terms of Aikman's Financial Stability Map: Financial stability without (right) and with (left) SIBs.

Lastly, we seek to answer the following question: Is the accumulated additional loss-absorbing capacity for SIBs enough to cover the losses themselves in case of a failure event? Figure 11 shows that it is insufficient for the self-coverage of losses. This has already been discussed in academic and policy platforms with the suggestion to increase the required capacity (see Passmore and von Hafften, 2019).

4 Conclusions

We extended the macroeconomic agent-based model in Popoyan et al. (2017, 2020) by including behavioral rules that will be characterizing the systemically important banks (i.e., dynamics bank-client network and relationship lending). We used the model to simulate SIBs and analyze the impact of higher imposed capital requirements on financial "giants" and see if this relatively new requirement ensures the safety and soundness of the financial system, and in case a SIB fails, loss-

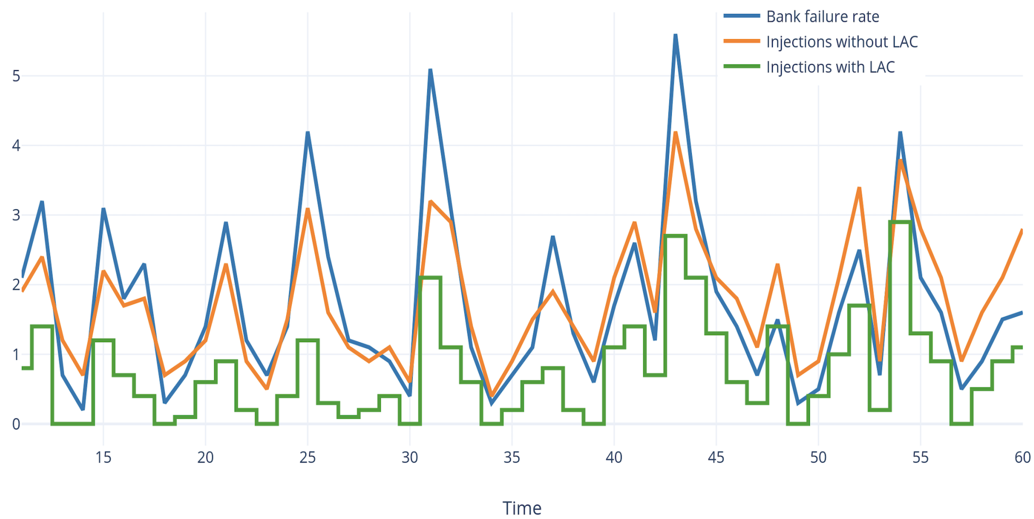


Figure 11: Additional loss-absorbing capacity (ALAC) and Government Injections

absorbing capacity can cover the losses and no intervention by government is needed. Additionally, we simulate the impact of 2 different combinations of macro-prudential constraints - Basel III with and without additional loss-absorbing capacity - and monetary policy rules to see the performance of capital requirements on SIBs in a full-fledged regulatory setup.

The model is able to generate systemically important banks (SIBs) endogenously. The model starts with a symmetric banking sector, with all the banks having more or less the same size, and the simulation allows the emergence of bigger and smaller banks. We have applied a Basel Committee's IBMA (BIS, 2013) for identifying the SIBs, accordingly imposing them to higher capital requirements. However, we found that the additional capital surcharges on SIBs proved to have a marginal or even negative effect on preventing the crisis, and they effectively work only when decoupled with the "leaning against the wind" monetary policy. In the search to understand this result, we found out that the IBMA mainly points to the size of the intermediary, giving a higher weight, hence pointing mainly to the "too-big-to-fail"(TBTF) problem with minimal importance for "too-interconnected-to-fail", "too-many-to-fail" and other issues. Moreover, such an approach overlooks the operational profile of the banks resulting in a "one-size-fits-all" problem. Finally, we found that additional loss-absorbing capacity is not enough to ensure total coverage of losses in case of failure SIBs, so the government, in one way or another, needs to intervene to bail the banks out. Those findings are in line with the evidence found in Suh (2019) and Passmore and von Hafften (2019).

The model creates an environment to analyze alternative measures of systemic importance and their efficiency in the financial system's safety and soundness. The future analysis will develop around testing the alternative measures (see Thomson, 2009; Poledna et al., 2017; Kleinow et al., 2017; Hué et al., 2019, for some of these measures). We can opt for an alternative approach that we believe best fits our setup, known as the "4C" approach of systemic importance proposed by (Thomson, 2009). The "4C"'s in this approach stand for (i) **C**ontagion, (ii) **C**orrelation, (iii)

Concentration and (iv) **C**onditions/**C**ontext. In contrast to IBMA, the “4C” approach puts an accent not only on the “too-big-to-fail” phenomenon but also on the “too-ineterconnected-to-fail” and “too-many-to-fail”.

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Appendix A The model

The appendix presents the detailed structure of the real side of the model and the fiscal policy discussed in Section 2 of the paper. We start with the entry procedure of the shops and the process of price and wage setting. Next, we discuss in detail the budget planning and portfolio choices of each type of agent, followed by search-and-matching mechanisms in labor and goods markets. Then, we present the relevant fiscal policy equations. Finally, we explain how the interbank market works, how the credit supply is satisfied and how the liquidity requirements work in the model.

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).[12] 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 ($y_{i,t}^{trg}$), and computes the price and the expected profits.[13] The price $p_{i,t}^{nor}$ is equal to

$$p_{i,t}^{nor} = \frac{(1+\mu_{i,t})}{(1-\tau)} w_{i,t}, \tag{15}$$

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:

$$\Pi_{i,t} = w_{i,t}(\mu_{i,t} y_{i,t}^{trg} - (F-1)) - w_{i,t} i_t^D (y_{i,t}^{trg} + F - 1) > 0, \tag{16}$$

where F stands for a fixed cost (expressed in units of shop owner's production good) 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:

$$w_{i,t} = W_t(1+\pi^*)^{\frac{\Delta+1}{2}}, \tag{17}$$

where W_t, Δ and π^* are the average wage rate across all shops computed as a ratio between aggregate wage and aggregate employment at time t, fixed contract period, and Central Bank's target inflation rate respectively.[14] The unemployed agent in a job search will accept the offer of the shop owner if the proposed wage is more than her effective wage (described in Eq. 22 below): $w_t^{eff} < w_{i,t}/(1+\pi^*)$.

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 ($p_{i,t}^{nor}$) is defined as follows:

$$p_{i,t}^{nor} = \frac{(1+\mu_{i,t})}{(1-\tau)} w_{i,t}, \tag{18}$$

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 $p_{i,t}^{nor}$ is less than the consumer's effective price (p_t^{eff}): $p_t^{eff} > p_{i,t}^{nor}/(1+\pi^*)$

Shops during their life will continue setting prices with the normal pricing rule stated in Eq. 18 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

[12] 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 in Eq. 7.

[13] 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 $[1; n]$.

[14] 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:

$$p_{i,t} = \begin{cases} p_{i,t}^{nor} * \delta_p, & \text{if } I < y_{i,t}^{trg} * IS^{-1} \\ p_{i,t}^{nor} * \delta_p^{-1} & \text{if } I > y_{i,t}^{trg} * IS \\ p_{i,t}^{nor}, & \text{otherwise} \end{cases} \tag{19}$$

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:

$$A_{i,t}^s = H_{i,t}^s + D_{i,t}^s + P_{h,t} * I_{i,t} - L_{i,t}^s < 0$$

A.2 Budget planning and portfolio choices

Agents of all types plan their budgets to hold enough money to spend it during the next stage. For this sake, each agent first decides his planned consumption expenditure. To prepare for this decision, agents adjust their permanent income by using the following adaptive rule:

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

where Y_z, Y_z^p and λ_p are, respectively, the actual income, permanent income, and the adjustment speed parameter.

Each agent sets planned consumption expenditure ($CE_{z,t}$) equal to a fixed fraction υ of total wealth (i.e., sum of financial wealth ($A_{z,t}$) and permanent income ($Y_{z,t}^p$)):

$$CE_{z,t} = \upsilon(A_{z,t} + Y_{z,t}^p).$$

Learning the retail prices of their two outlets (p_1, p_2) agents choose their desired consumption bundle ($c_1; c_2$) to maximize the utility function below subject to $p_1 c_1 + p_2 c_2 = CE$ budget constraint:[15]

$$u(c_1, c_2) = c_1^{\varepsilon/(\varepsilon+1)} + c_2^{\varepsilon/(\varepsilon+1)}, \tag{20}$$

where $\varepsilon > 0$ stands for the demand parameter. Quantities c_1 and c_2 are accordingly the quantities of primary and secondary consumption goods agent orders while engaging in goods market trading (see also Goods market in Appendix A.3).

The financial wealth of a consumer/worker who does not own a shop or a bank is:

$$A_{c,t} = H_t^c + D_t^c + P_f * I_t^c,$$

where H_t^c are cash holdings, D_t^c stands for bank deposits and $P_f * I_t^c$ is the value of inventories in the fire-sale market.

The financial wealth of shop owner is:

$$A_{s,t} = H_t^s + D_t^s - L_t^s,$$

where H_t^s are cash holdings , D_t^s stands for bank deposits and L_t^s are outstanding loans.

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

$$A_{b,t} = H_t^b + (E_{m,t}^b - \overline{\epsilon_b}(L_{m,t}^s + SC_{m,t} + 0.2IB_{m,t}),$$

In the above expression H^b denotes cash holdings and $(E_{m,t}^b - \overline{\epsilon_u}(L_{m,t}^s + SC_{m,t}^b + 0.2IB_{m,t}^b)$ denotes instead the bank's equity after subtracting regulatory capital.[16].

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

[15] Note that $CE = \upsilon(A + Y^p) = p_1 c_1 + p_2 c_2$.

[16] The balance-sheets of all the types of agents are reported in Table 5 in Appendix C. Notice that the model is stock-flow consistent (see, e.g., the seminal contribution of Godley and Lavoie, 2007).

the constraint:

$$D_t^c = (1 + i_t^D)(\overline{H}_t^c + \overline{D}_t^c - H_t^c).$$

If $CE_{c,t} \leq \overline{H}_t^c + \overline{D}_t^c$, then the worker fixes $CE_{c,t} = H_t^c$ and leaves the residual in her bank account. Otherwise, $CE_{c,t} = H_t^c = \overline{H}_t^c + \overline{D}_t^c$.

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

Finally, consider the portfolio management of a shop owner. Except for money (H^s) and deposits (D^s), a shop owner can apply for a loan (L^s). If the shop has already a currently rolling credit line and her bank is not troubled, her credit limit will be equivalent to the haircut value of her eligible collateral (determined in Eq. 7). Consequently, the financial constraint of a shop owner's is as follows:

$$\begin{aligned} &H_t^s - \overline{H}_t^s = \overline{D}_t^s - \tfrac{D_t^s}{1+i^D} + \tfrac{L_t^s}{1+i^L} - \overline{L}_t^s, \\ &L_t^s \leq P_{h,t}(I_t^s + S)(1 + i^L). \end{aligned}$$

where $H_t^s \geq 0$, $D_t^s \geq 0$, $L_t^s \geq 0$ and where $\overline{H}^s$, $\overline{D}^s$ and $\overline{L}^s$ are respectively, the current levels of cash, deposits, and bank loans. The above-mentioned constraints are met, and the loan is paid if $\overline{H}_t^s + \overline{D}_t^s + P_{h,t}(I_t^s + S) \geq \overline{L}_t^s$.

A.3 Labor and goods market trading

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

Labor market. The wage of the shop is set according to Eq. 21. 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 based on the following rule:

$$w = \overline{w}\left[\left(1 + \beta\left(\overline{x^{trg}}/\overline{x^{pot}} - 1\right)\right)(1 + \pi^*)\right]^{\Delta/48}, \tag{21}$$

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:

$$w_t^{eff} = min(w_{i,t}, H_{i,t}), \tag{22}$$

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. Before the actual goods market trading takes place, a store search is undertaken by every agent. The agent picks at random a shop producing and trading his primary consumption good and checks that shop's sales price (p). The agent then switches to this new shop if $p^{eff} > p/(1 + \pi^*)$, where p^{eff} represents the effective price he experienced last period, p is the shop's latest posted price, and π^* target inflation rate. Switching a shop implies cancelling the pre-existing customer relationships of the agent and forming a new one with a newly selected shop. The same search procedure is repeated for the secondary consumption good of the agent. Goods market trading then unfolds as follows. If the shop's available inventory (I) of the agent's primary and secondary goods are enough, the consumer can place an order for each good for an amount c_s (see Appendix A.2 for details), subject to the cash-in-advance constraint $p_s c_s \leq H$, where p_s is the posted sales price (see Eq. 19) and H is the person's money holding (see Appendix A.2 for the agents budgeting decisions).[17] The shop then gives the agent an amount $c_s^{eff} = min(c_s, I)$ in

[17]Note that if cash is not enough, consumers give priority to the primary good over the secondary one.

exchange for the amount $p_s c_s^{eff}$ of money. The consumer's effective price for that good is defined as the following: $p_s^{eff} = p_s * c_s / c_s^{eff}$.

Firesale markets. The firesale market is composed of buyers and sellers. The sellers (supply side) is composed of banks selling seized collateral, and former shop owners liquidating their inventories. The buyers (demand side) of the market is formed by shops, whose actual level of inventories are below of their inventory target. A buyer is matched to the first seller (if any) in the queue. If the first seller in the line cannot fulfill the entire order, the shop buys from the second supplier, and so on, until either the request is satisfied or the queue runs out of suppliers. Buyers pay their orders with deposits (if any) and then, if necessary, with credit.

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 the 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 credit supply

Banks need to satisfy the minimum capital requirement:

$$\frac{E^b_{m,t}}{RWA_{m,t}} \geq \overline{\epsilon_3}$$

where $\overline{\epsilon_3}$, is regulatory minimum imposed by the Central Bank according to Basel III setup, E_b is the bank capital and RWA is the bank's risk-weighted assets. Bank at the beginning of the stage computes how much capital (E_b) they need to keep to satisfy the risk-weighted capital requirement ϵ_3. Accordingly one gets:

$$\frac{E_b}{RWA} \geq \overline{\epsilon_3} \Rightarrow E_b \geq \overline{\epsilon_3} * RWA \Rightarrow RWA \leq \frac{1}{\overline{\epsilon_3}.}$$

Given this relationship, one can derive reserve of exposures constraint to compute the supply of loans ($L^{sup}_{m,t}$) that banks can still provide to firms in the form of commercial loans:

$$L^{sup}_{m,t} = \frac{1}{\overline{\epsilon_u}} * E^b_{m,t} - RWA_{m,t}.$$

Knowing that RWA is the equal to $\psi_{IB} IB_{m,t} + \psi_L L^s_{m,t} + \psi_{SC} SC_{m,t}$ (see Eq. 13), one gets exactly the Eq. 3 in the manuscript.

A.6 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 of 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.[18]

[18]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 the bank's total HQLA.

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 their corresponding run-off (for liabilities) and default (assets).[19] 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, $NCOF_{m,t} = Ex[O^{b(-)}_{m,t}] - min(Ex[O^{b(+)}_{m,t}; 0,75 * [O^{b(-)}_{m,t}])$.

A.7 Interbank Market

The engagement of banks in interbank market is connected to liquidity regulations. 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 2.5 below):

$$l_{m,t} = \frac{HQLA_{m,t}}{NCOF_{m,t}} \geq \bar{l}. \tag{24}$$

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

$$IB_t = IB^{qk}_t \in R^{m\times m} = \left[\begin{array}{cccc|c} IB^{11}_t & IB^{12}_t & \cdots & IB^{1m}_t & IB(L)^1_t \\ IB^{21}_t & IB^{22}_t & \cdots & IB^{2m}_t & IB(L)^2_t \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ IB^{m1}_t & IB^{m2}_t & \cdots & IB^{mm}_t & IB(L)^m_t \\ \hline IB(A)^1_t & IB(A)^2_t & \cdots & IB(A)^m_t & \end{array}\right] \tag{25}$$

Each entry IB^{qk}_t 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 ($IB(L)^q_t$), 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 ($IB(A)^k_t$).

[19]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).

The matching of liquidity demand and supply is made by Central Clearing Counterpart, accordingly sorting banks demanding liquidity and those supplying liquidity in descending order. In this way, the first bank on the demand side has the highest liquidity demand (for more details refer to (Popoyan et al., 2020)).

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 "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 2.5), and $\phi_l > 0$ and $\phi_d > 0$ are the parameters defining the width of the corridor. Note that in the case of the 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

$$\Theta_t = \frac{\sum_{k=1}^{m} IB^{sup}_{k,t} - \sum_{n=1}^{m} IB^{dem}_{n,t}}{\sum_{n=1}^{m} IB^{dem}_{n,t}}. \tag{26}$$

The common component of the interbank rate will fall in the interval $[i, i + \phi_l]$ whenever $\Theta < 0$. In contrast, $i^{IB}_{corr} \in [i - \phi_d, i]$ if $\Theta > 0$. Finally, $i^{IB}_{corr} = i$ when $\Theta = 0$. 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:

$$ib_{m,t}(i_t, \varepsilon_i, \Theta_t) = \begin{cases} i_t + \varepsilon_{i,t}, & \text{if } \Theta_t = 0 \\ i_t + \phi_l - \iota * \Theta_t + \varepsilon_{i,t}, & \text{if } \Theta_t < 0 \\ i_t - \phi_d + \iota * \Theta_t^{-1} + \varepsilon_{i,t}, & \text{if } \Theta_t > 0 \end{cases} \tag{27}$$

with $0 < \iota < 1$ capturing banks' propensity to lend. Accordingly, for a bank m (in need of reserves) the interbank rate paid depends on the policy rate (i_t), on the current financial soundness of the bank ($\varepsilon_{i,t}$) and the current supply of excess reserves expressed by Θ_t thus assuring that banks seek money first in the open interbank market before turning to the CB's standing facilities.

Appendix B Parameters

Table 4: Parameters of the model

Parameter	*Description*	*Value*
	Macro-prudential Regulation Parameters	
$\overline{\alpha}$	Leverage requirement	0.03
$\bar{l}$	Liquidity requirement	1
$\overline{\epsilon_3}$	Minimum capital requirement in Basel III	0.045
κ	Counter-cyclical capital buffer	$[0, 0.025]$
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
ψ_L	Risk-weight for commercial loan	1
ψ_{IB}	Risk weight for interbank loan	0.2
ψ_{SC}	Risk-weight for seized collateral	1
	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 from 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_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	0.7
	Workers/Consumers Parameters	
ε	Demand parameter	7.0
υ	Propensity to consume	0.56
λ_p	Permanent income adjustment speed	0.4
θ	Frequency of innovation	100
σ	Job search probability	0.5
N	Number of population	4760
	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	48
n	Number of goods	50

Appendix C The balance-sheet matrix of the model

Table 5: 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.*