Interbank credit and the money manufacturing process. A systemic perspective on financial stability

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Abstract

Interbank lending and borrowing occur when financial institutions seek to settle and refinance their mutual positions over time and circumstances. This interactive process involves money creation at the aggregate level. Coordination mismatch on interbank credit may trigger systemic crises. This happened when, since summer 2007, interbank credit coordination did not longer work smoothly across financial institutions, eventually requiring exceptional monetary policies by central banks, and guarantee and bailout interventions by governments. Our article develops an interacting heterogeneous agent-based model of interbank credit coordination under minimal institutions. First, we explore the link between interbank credit coordination and the money generation process. Contrary to received wisdom, interbank credit has the capacity to remove the inner limits of monetary system capacitance. Second, we develop simulation analysis on imperfect interbank credit coordination, studying impact of interbank dynamics on financial stability and resilience at individual and aggregate levels. Systemically destabilizing forces prove to be related to the working of the banking system over time, especially interbank coordination conditions and circumstances.

Highlights

- An interacting heterogeneous agent-based model under minimal institutions is developed to study bank credit, money creation and interbank credit
- Interbank credit makes the money generation process unbound in some circumstances
- Financial stability depends on both bank and inter-bank credit conditions and circumstances

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1 Introduction

During recent decades before the global financial crisis, mainstream economic theory had quite neglected the role of money and credit in economy and society (Jakab and Kumhof, 2015; Werner, 2014a,b). In particular, macroeconomic theory was drawing upon the real business cycle approach, developing Dynamic Stochastic General Equilibrium (DSGE) models where money and credit did not play a significant role (Blanchard, 2009; Stiglitz and Gallegati, 2011; Romer, 2016; Delli Gatti et al., 2010; Blanchard et al., 2010). In this context, banking was understood as a mechanic process that merely dispatches central bank base money to non-financial, real-economic agents who need borrowing. Moreover, banking theory was developing principal-agent approaches that introduced contractual arrangements and incentives in the bank entity structure while relegating bank money generation function outside banking theoretical core (Calorimis and Kahn, 1991; Diamond and Rajan, 2001; Diamond and Dybvig, 1983; Gorton and Pennacchi, 1990). At the same time, financial economics was developing a market-based finance theory where banks were considered as portfolio managers quite analoguous to other investment funds and submitted to financial markets discipline (Tobin, 1963; Black, 1970; Fama, 1980; Hall, 1983). From these perspectives, banking come to be understood as pure intermediation of available funds between savers who wish to invest those funds, and borrowers who need borrowing them.

Evidence from the global financial crisis of 2007-08 has been renewing theoretical interest in the role of banking, money and credit in economic and financial dynamics. While the crisis was accidentally triggered by rising actual and expected defaults in some bank asset categories, the origins of the global financial meltdown were found in systemic fragilities related to bank excess behaviours and the overarching dynamics of interbank credit, leading to central bank interventions and government bailouts to protect financial stability and assure financial resilience (BoE, 2008). Interbank lending and borrowing occur when financial institutions seek to settle and refinance their mutual positions over time and circumstances. This interactive process involves money generation at the aggregate level. Coordination mismatch on interbank credit may trigger systemic crises. This happened when, since summer 2007, interbank credit coordination did not longer work smoothly across financial institutions around the world, eventually requiring exceptional monetary policies through central bank coordination (Ricks, 2016; Blair, 2013; Gorton, 2010; Singh, 2014).

Recent studies have been investigating the role of money, credit and interbank credit networks in the working of the financial system, including when financial crises occur. Martnez-Jaramillo et al. (2010) and Caccioli et al. (2015) develop simulation models that relate interbank dynamics with systemic risk. Matsuoka (2012) provides a monetary model for understanding the role of lender of last resort (i.e.: central banks) in an economy with an imperfect interbank market. Anand et al. (2012) address the heavy reliance on short-term wholesale funding markets in a vastly and increasingly connected financial system during the global financial crisis of 2007/2008, leading to a dramatic increase in rollover risk at the system level. Further studies focus on the interbank credit network structure and the financial linkages between banks, often applying agent-based simulations (Krause and Giansante, 2012; Teteryatnikova, 2014; Bech et al., 2015; Capponi and Chen, 2015).

Many studies apply agent-based modelling (ABM) to analyze the interbank credit dynamics. Huang et al. (2010) apply an ABM to examine various types of financial crises. Galbiati and Soramaoki (2011) propose an ABM of interbank payment systems under real-time gross settlement modality that seems to be vulnerable to liquidity risk. To their knowledge, it is the first paper to explore liquidity management in such a system using an agent-based approach. Other ABM are applied to explain: the formation, evolution and stability of interbank market (Iori et al., 2006; Xu et al., 2016; Ladley, 2013); the emergence of network structure (e.g.: core-periphery) (Lux, 2015); the linkage between the interbank market and the real economy (Gabbi et al., 2015); the repercussions of inter-bank connectivity on bank performances, bankruptcy waves and business cycle fluctuations (Grilli et al., 2015); the role of trading memory or trust in the interbank relationships (Iori et al., 2015; Temizsoy et al., 2015; Bulbul, 2013); the behavior of bank leverage (Fischer and Riedler, 2014; Aymanns and Farmer, 2015); the role of stabilizing institutional arrangements based on socioeconomic roles and leaderships (Gilles et al., 2015); the bank default and resolution (Klimek et al., 2015). More generally, Bargigli and Tedeschi (2014) review some basic concepts and instruments in a wide range of economic network models.

Pointing to the link between the banking system and real economy, Delli Gatti et al. (2010) model a macroeconomic credit network consisting of households, firms and banks, in view to study the occurrence and likelihood of bankruptcy avalanches. Battiston et al. (2012), Riccetti et al. (2013), Bargigli et al. (2014), and Catullo et al. (2015) extend this work. Lux (2016) and Anand et al. (2013) develop stochastic models of the topology of bank-firm credit networks. He et al. (2016) design an endogenous credit network model that describes the formation of firm-firm, firm-bank and bank-bank credit relationships. Moreover, Delli Gatti and Desiderio (2015) and Beck et al. (2014) apply ABM to explore the effects of monetary policy. Their simulations show its clear non-neutrality and transmission mechanism in the credit channel.

Valencia (2014) discusses a similar issue. Gabbi et al. (2015) focus on the linkage between the inter- bank market and the real economy with a stylized central bank acting as a lender of last resort. Our article contributes and expands on these analyses by paying specific attention to the way banks perform credit creation along with inter-bank credit, clearing, and payment settlement.

Concerning modeling the money generation process, Xiong et al. (2017) develop a multi-agent model describing the main mechanisms of money creation and money circulation in a credit economy. Similarly, Chen et al. (2014) examine the money generation process in a random exchange model with debt between agents. Our article expands on these analyses by combining payment and credit systems, while introducing endogenous money generation through bank credit and interbank credit.

Our article contributes to recent literature by taking a systemic perspective, aiming to overcome received limited understanding of the systemic links between money, credit and banking. Some facts feature modern banking: monetary financial institutions (banks) issue claims which function as money; they facilitate payments across agents in the economy over time and space; they increase the money base through credit creation; they hold fractional reserves and lend to each other (Blair, 2013; Ricks, 2016; Jakab and Kumhof, 2015). Our systemic perspective points to these featuring dimensions of ongoing bank activity within each bank entity and across them. Each bank entity keeps currency money in bank deposits on behalf of other agents. But the bank entity activity is further characterized by its capacity or privilege to use these deposits, although the latter remain available for payment and redemption at will and at par. Moreover, the bank can create a deposit by granting a loan to, or buy a security from a borrower. This bank capacity or privilege involves money multiplication that enables bank credit creation process over space and time. In this way, all the banks become interdependent on the flow of payments that are performed across them, generating a 'banking system' (Biondi, 2018).

This banking dynamic system requires coordination within each bank and across them. Within each bank entity, two featuring processes are at work: (i) An economic process that creates bank money through credit, in view to generate income to the bank entity; and (ii) a financial process that rebalances cash inflows and outflows when they become due through space and time. Since each bank is structurally unbalanced due to money multiplication, interbank coordination is required to maintain the banking system in operation over time and circumstances. Interbank clearing, settlement and credit arrangements feature this interbank coordination which occur under various institutional arrangements, such as central banking, central clearing parties, and money markets. Interbank coordination management is concerned with counterparty risk, funding risk, settlement risk, margin risk, liquidity risk and payment risk, that is, risks, uncertainties and hazards related to interactions and relationships across banks. From this perspective, our conceptual framework embeds heterogeneous agents into two collective dynamics: inter-agent interaction, and interaction between collective structures and individual agents. These structures are consistent with the notion of 'minimal institution' introduced by Shubik (2011) and Shubik and Smith (2016).

The rest of the article is organised as follows. Drawing upon this conceptual frame of reference, we develop an interacting heterogeneous agent-based model of interbank credit coordination under a set of minimal institutions (Section 2). First, we explore the theoretical link between interbank credit coordination and the money generation process (Section 3). Second, we develop simulation comparative analysis on modes of interbank credit coordination, studying impact of interbank dynamics on financial stability and resilience at individual and aggregate levels (Section 4). Systemically destabilising forces prove to be related to the working of the banking system over time, especially interbank coordination conditions and circumstances. A summary of main findings and implications concludes (Section 5).

2 Agent-based dynamic modelling of the banking system

According to Xiong et al. (2017), the textbook story of money creation tells that the quantity of loans that commercial banks may possibly grant is constrained by the quantity of central bank base money (central bank reserves, comprising currency and drawing facilities) and the required reserve ratio. This story is consistent with fractional reserve lending of loanable funds, where, period through period, each lending bank department is restricted to lend out only a fraction of available cash in hand. Under fractional reserve requirement, money is therefore created through a gradual, ad infinitum mechanical process of 'lending out' and 'depositing in' of cash in hand (narrow banking). This modelling strategy has been often criticised to neglect space and time of money generation process, implying a reductionist view on its idiosyncratic, interactive, collective and dynamic dimensions. In particular, this view makes banking system coordination virtually irrelevant.

Our model extends and upgrades on this received understanding by drawing upon the functional equivalence between currency and deposit. From this functional perspective, money can be created both by issuing cash and cash-equivalent securities (that is, financial entitlements that circulate and function like cash does), and by creating drawing facilities (bank deposits) that promise to be redeemable in cash and cash-equivalents. In this context, banking, money and credit are fundamentally linked one to another. When a bank lends to a borrowing client, bank balance sheet simultaneously expands with the loan (an asset to the bank) and the deposit (a liability to the bank), both relating to that customer, while the bank promises to make the customer deposit redeemable in cash and cash equivalents (especially other banks' deposits). When the borrowing client repays its loan to the bank, the loan capital instalment reduces the customer's exposure (an asset reduction to the bank), while the bank does either acquire a different kind of asset (if settlement is performed by cash transfer), or reduce its deposit liability (if settlement is performed through customer's deposit).

Our story replaces fractional reserve lending with a money multiplication process. The bank treasury department seeks to rebalance movements in cash and cash equivalents that become due for settlement-related and credit-related payments, while the bank lending department levers upon cash and cash-equivalent holdings to create new loans. To disentangle the systemic connection between payments, bank credit and inter-bank credit, we develop an agent-based model comprising three functional steps that each bank passes through when managing its relation with customers and with the other banks. These dynamic steps correspond to ongoing dimensions of the banking system: (i) payments system (Section 2.2), (ii) bank credit creation and destruction with customers (Section 2.3), and (iii) interbank settlement and credit system (Section 2.4).

Figure 1 summarises the model timing where these three dimensions combine and operate. After initialisation ($\tau = 0$), the flow of payments is performed across customer accounts, while involved banks settle these payments through two distinctive procedures ($\tau = 1$). At the next step ($\tau = 2$ and 3), past customer loans are repaid while new ones are granted according to two alternative lending strategies that are based upon the available reserves in distinctive ways (respectively labeled money multiplication and fractional reserve). At the third step ($\tau = 4$ and 5), evolving networks of banks pool available reserves together according to the respective reserve need and excess at that point of time. This pooling mechanism depends on interbank coordination quality and bank outstanding positions, both evolving over time and circumstances captured by the parameter space.

2.1 Setting the scene (INITIALISATION)

Our miniature financial system comprises the following agent types:

◇ A whole of customers $\{c_j, j = 1...C\}$, which order payments over time periods t, while asking for bank loans and repaying them over time periods $h >= t$. For the sake of simplicity, we may assume that $h = t$ without generality loss.

◇ A system of monetary financial institutions (banks) $\{b_i, i = 1...B\}$, which perform payments on behalf of other agents, and grant credits to customers and to each other.

◇ One Central Bank, which issues an exogenous quantity of currency $A1$ and acts as guarantor of last resort if one bank remains exposed to other banks after interbank settlement and

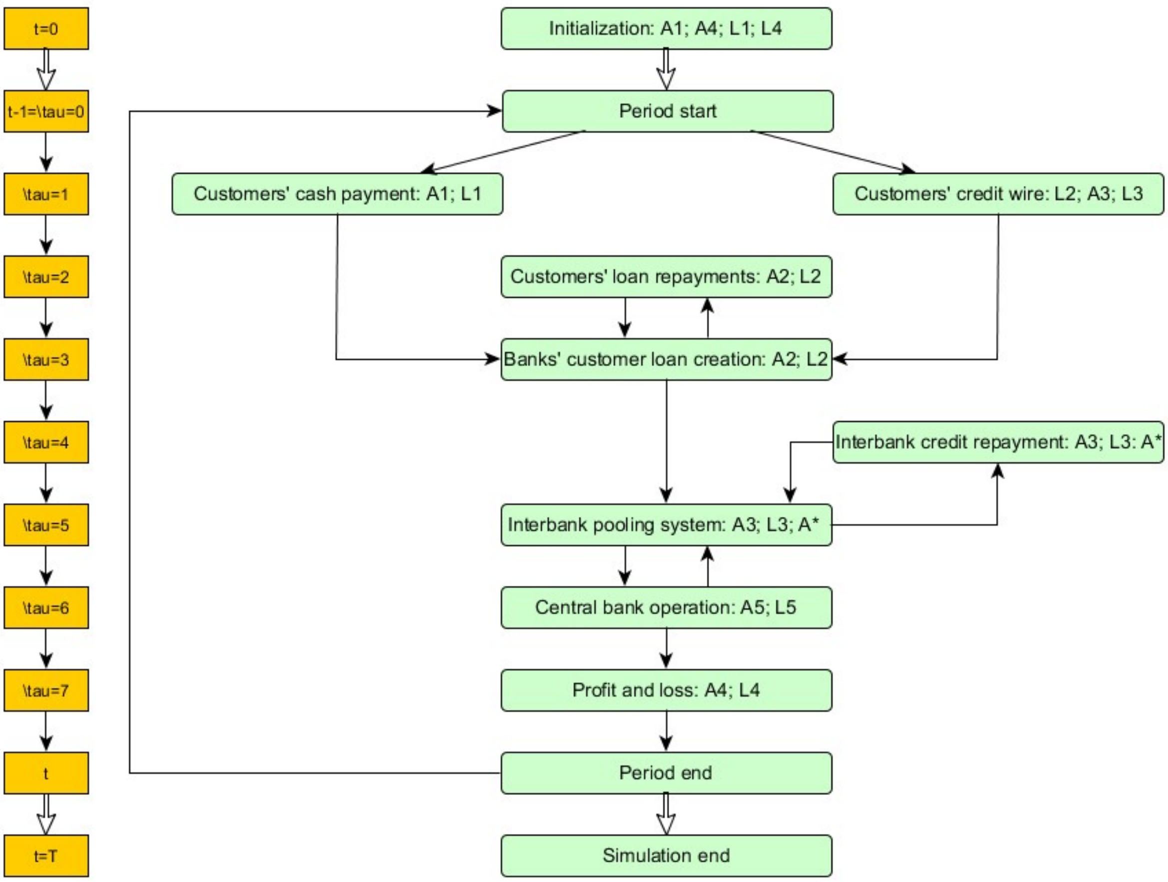

Figure 1: *Flowchart summarizing the model structure and steps.*

credit.

Each bank balance sheet contains five kinds of assets and related liabilities (Table 1).

Table 1: Bank balance sheet items

Asset	Liability
A1: Currency Reserves	L1: Deposit (Base Money)
A2: Retail Loan	L2: Deposit (Retail Loan)
A3: Interbank Lending	L3: Interbank Borrowing
A4: Equity Reserve	L4: Equity Provision
A5: Central Bank Assistance	L5: Central Bank Guarantee

Concerning initialization, we distribute every customer j's deposit ($l1_{i,j,t}$) to any bank i randomly. The initial amount of base money $A1_0$ is split equally across customer deposits ($l1_{i,j,t} = A1_0/C$). Moreover, total equity $A4_0$ is allocated equally across banks ($A4_{i,t} = L4_{i,t} = A4_0/B$).

The following individual bank balance sheet identity holds at every time period t (including initialization step $t = 0$):

$$\begin{aligned} A1_{i,t} + A2_{i,t} + A3_{i,t} &= L1_{i,t} + L2_{i,t} + L3_{i,t} \\ A4_{i,t} &= L4_{i,t} \\ A5_{i,t} &= L5_{i,t} \end{aligned} \tag{1}$$

This miniature economy has a total base money $A1 = \sum_i^B A1_{i,t=0} = \sum_i^B \sum_j^C l1_{i,j,t=0}$ that is distributed equally to C customers, and a total bank capital $\sum_i^B L4_{i,t=0}$ that is distributed equally to B banks. Customers deposit all of their money to individual banks, based on a fixed transition/selection matrix $M_{C\to B} = (m_{c_j \to b_i})_{C\times B}$ (where $m_{c_j\to b_i} = 1$ if b_i is the bank of c_j, else $m_{c_j\to b_i} = 0$). At time $t = 0$, the initial capital $L4_{i,t=0}$ of bank i is provided, which also adds to its initial equity reserve $A4_{i,t=0}$ (the size of banks can be calibrated equally or follow some distribution in line with empirical evidence). The initial total deposit from customers $c_{j,j\in\{C\}}$ to their bank $b_{i,i\in\{B\}}$ is $L1_{i,t=0} = \sum_j l1_{i,j}$ where deposited currency is issued by the central monetary authority (assuming all customers' money is stored in banks, no cash in hand outside the banking system), adding to the initial base money cash reserve $A1_{i,t=0}$ of bank i (the initial money deposit by customers can be calibrated equally or follow some distribution in line with empirical evidence). There is no initial loan to customers $A2_{i,t=0} = 0$ and $L2_{i,t=0} = 0$, no interbank lending $A3_{i,t=0} = 0$ or borrowing $L3_{i,t=0} = 0$, no central bank assistance $A5_{i,t=0} = 0$ or guarantee $L5_{i,t=0} = 0$. Therefore, the initial individual bank balance sheet identity is:

$$\begin{aligned} A1_{i,t=0} &= L1_{i,t=0} \\ A4_{i,t=0} &= L4_{i,t=0} \end{aligned} \tag{2}$$

where $A1_{i,t=0} = L1_{i,t=0} = \sum_j l1_{i,j,t=0}$ and $l1_{i,j,t}$ is a customer j's individual cash deposit in own bank i at time t.

Since our analysis focuses on financial stability implications of interbank coordination, we assume that equity (A4/L4) and central bank (A5/L5) provisions are non-cash based, that is, they do not modify reserve base holdings and obligations over time and circumstances. A further extension may consider an additional set of minimal institutions to design and implement equity payments and central bank monetary interventions.

Concerning bank equity capitalisation, for the sake of simplicity and in line with Delli Gatti et al. (2010), we fix the number of banks and customers (i.e. exogenous) and we allocate equity capital equally across banks. Simulations start from identical initial conditions, but agents become rapidly heterogeneous throughout interactions. In some circumstances, banks may experience losses and then exhaust their initial equity provision. For the sake of simplicity, we let survive and keep operating banks with negative equity, using total equity loss as an indicator of financial distress for the single bank and the financial system as a whole. On the contrary, Delli Gatti et al. (2010) replace defaulted banks with new banks having small capital relative to the size of other solvent banks.

The model further disentangles ongoing banking activity through a sequence of three dynamic modules: (1) *Payments flow* (money circulation across customers, where banks facilitate payments over space and time); (2) *Lending to real economy* (banks are loan creators through long-term retail loans); (3) *Interbank coordination* (through both interbank credit, and central bank assistance as a residual balance device).

2.2 Model Module 1: Payments system

In our miniature economy, customers c_j may use currency $A1$ to perform payments across them. When this occurs, the bank of the customer x which orders to pay does transfer customer currency reserve $A1_{x,t}$ while reducing customer currency deposit $L1_{x,t}$. Conversely, the bank of the customer y which receives the payment does increase the customer currency deposit $L1_{y,t}$ and customer currency reserve $A1_{y,t}$. In this way, banks act as passive fiduciary depositors of customer holdings of currency.

Moreover, due to functional equivalence between cash and bank deposit, customers c_j may use their bank deposit $L2_{j,t}$ to perform payments. Customer bank deposits are created when their bank grants a loan $A2_{j,h}$ to them. When bank deposit wire transfer occurs, the bank of the customer x which orders to pay does reduce the customer bank deposit $L1_{x,t}$ by requested payment amount. Conversely, the bank of the customer y which receives the payment does increase the customer bank deposit $L1_{y,t}$. However, by assumption, banks do not transfer currency reserves against bank deposit transfers. Instead, banks agree to grant interbank lending and borrowing of same amount. The payer's bank then borrows from the payee's bank, adding to its interbank liability $L3_{x,t}$, while the payee's bank lends to its paying counterparty, adding to its interbank loan portfolio $A3_{y,t}$. This mechanism reproduces the settlement mechanism that is generally in place for banks through central bank facilities (McLeay et al., 2014; Rule, 2015).

Initial exogenous quantity of central bank currency $A1_0$ was equally distributed across customers and it now moves stochastically across them through time periods t. All cash holdings $A1$ are held by financial institutions. Payments across customers settled in currency are generated through a random markov transition matrix across customer bank accounts.

Customers perform two kinds of payments in this module: (1) cash payments through currency transfers from the banks of paying customers to the banks of receiving customers (i.e. updating both $A1_{i,t}$ and $L1_{i,t}$ in the banks' balance sheet); (2) bank wire transfers that pay through bank deposits $L2_{i,t}$ rather than transferring cash.

2.2.1 Customers' cash payment (A1/L1 update)

When modeling the first kind of payment (i.e. cash), a stochastic Markov transition matrix $\widetilde{M}_{c_x \to c_y}$ is used to describe the transition of cash payments across the customers' whole C. Each of its entries $\tilde{m}_{x \to y}$ represents the probability of a customer $c_x, x \in C$ to pay another customer $c_y, y \in C$, therefore $0 \leq \tilde{m}_{x \to y} \leq 1$ and $\sum_y \tilde{m}_{x \to y} = 1$. (This means that the sum of each row in $\widetilde{M}_{c_x \to c_y}$ is the total pay-out from a customer's existing cash deposit, and the sum of each column is the total pay-in from other customers that adds to a customer's next total deposit.) A parameter $\xi_1 \in [0, 1]$ controls the scale of customers' cash payment. This design implicitly assumes that customers are constrained by their cash deposit. Also, their net cash flow (resulting from balance between cash payable and receivable) is both small and stochastic over time.

Hence, across customers:

$$\{c_x\} \xrightarrow{\xi_1} \{\widetilde{M}_{c_x \to c_y}\} \longrightarrow \{c_y\} \Rightarrow \Delta l1_{x \to y,t} \tag{3}$$

In parallel, the bank of customer c_x transfers an amount $\Delta l1_{x \to y,t}$ of A1 to the bank of customer c_y, and reduces the cash deposit of c_x accordingly. In aggregate, every bank performs netting between total cash-in and cash-out, updating both sides of their balance sheet as follows:

$$\Delta A1_{i,t} = \Delta L1_{i,t} = \sum_{y \in \{\tilde{m}_{y \to x} > 0\}} \Delta l1_{y \to x,t} \quad - \sum_{x \in \{\tilde{m}_{x \to y} > 0\}} \Delta l1_{x \to y,t} \tag{4}$$

where c_x is the customer of bank i and c_y may be any customer of other banks.

2.2.2 Customers' bank credit wire transfer (L2 and A3/L3 update)

Concerning the second kind of payment (i.e. bank loan deposit wire transfer), a similar stochastic Markov transition matrix is used to describe the wire transfer payment transitions. In this case, customers use their loan deposits $l2_{i,j,t}$ to perform their payments.

Therefore, among the customers:

$$\{c_x\} \longrightarrow \{\widetilde{M}_{c_x \to c_y}\} \longrightarrow \{c_y\} \Rightarrow \Delta l2_{x \to y,t} \tag{5}$$

However, there are two differences with cash payment transfers: (1) Although the payments are exchanged between customers, the actual net of credit transactions are across banks. Therefore, a new transition matrix $\widetilde{M}_{b_u \to b_v}$ is used to model the interbank credit net transition (i.e.: the net of total customer deposits in and out a certain pair of banks (u, v)). (2) Since customers can borrow from their banks to pay other customers through bank credit, they are constrained by the loan $l2_{i,j,t}$ granted by their own banks. A parameter $\xi_2 \in [0, 1]$ controls the scale of this transition.

$$\{b_u\} \xrightarrow{\xi_2} \{\widetilde{M}_{b_u \to b_v}\} \longrightarrow \{b_v\} \Rightarrow \Delta L2_{u \to v,t} \tag{6}$$

where $\Delta L2_{u \to v,t} \leq L2_{u,t}$ for all banks. Each pair of banks perform clearing and settlement of these wire payments in two steps. First, the two banks net mutual opposite positions against each other. Second, they agree to transform the net residual difference in interbank lending and borrowing.

Therefore, the netting transaction between any pair of banks (u, v) is:

$$\Delta L2_{u,v,t} = \Delta L2_{u \to v,t} - \Delta L2_{v \to u,t}, \quad \forall (u, v), t \tag{7}$$

where each bank pair (u, v) deposit movement from bank to bank is the sum of customers in one bank paying to customers in the other bank. For instance, for payments from bank u to bank v: $\Delta L2_{u \to v,t} = \sum_{c_x \in b_u, c_y \in b_v} \Delta l2_{x \to y,t}$. In aggregate, every bank sums up all these net wire payments with other banks and updates its $L2_{i,t}$:

$$\Delta L2_{u,t} = \sum_{v \in \{\tilde{m}_{u \to v} > 0\}} \Big(\Delta L2_{u \to v,t} - \Delta L2_{v \to u,t} \Big) \tag{8}$$

if $\Delta L2_{u,t} > 0$, then bank u increases its L2, else if $\Delta L2_{u,t} < 0$, then it decreases its L2. In parallel, banks update their interbank credit (A3 and L3) across them:

$$\begin{cases} \Delta A3_{u,t} = \Delta L2_{u,t}, & \text{if } \Delta L2_{u,t} > 0 \\ \Delta L3_{u,t} = -\Delta L2_{u,t}, & \text{if } \Delta L2_{u,t} < 0. \end{cases} \tag{9}$$

These new amounts of interbank credit are recorded as a pair (u, v) between every two banks. They add to the other A3 and L3 that will be created in the interbank credit pool network and repaid all together later on.

2.3 Model Module 2: Bank credit creation and destruction

While dealing with the payments system on behalf of its customers, each and every bank experiences that an ongoing core of its reserve holdings $A*_{i,t} \in \{A1_{i,t}, A2_{i,t}, A3_{i,t}\}$ remains relatively stable over time. Under the functional equivalence between currency and deposit, every bank acquires the capacity or the privilege to use these holdings, while they remain available to the agents that have borrowed from the bank. Its borrowers may be either its customers $\{L1_{j,t}, L2_{j,t}\}$ or other banks $(L3_{j,t})$. This implies that the bank holds an ongoing safety net on which its lending activity may lever upon.

For the sake of simplicity and without loss of generality, we assume that each bank lending department does plan to lend to its customers only. Before seeking to grant new loans, each bank receives loan repayments from customers which borrowed in the past.

2.3.1 Customers' loan repayments (A2/L2 update)

In line with bank loan repayment mechanism introduced by Xiong et al. (2017), customers loan repayment follows the following procedure. Generating a stochastic repayment ratio $\widetilde{\Psi}_{i,t}$ for each bank based on a Triangular Distribution (depending on the lower ψ_L, peak ψ_P and upper ψ_U parameters):

$$\widetilde{\Psi}_{i,t}(\psi_L, \psi_P, \psi_U) \sim Triangular(\psi_L, \psi_P, \psi_U) \tag{10}$$

The loan is repaid based on the following repayment formula:

$$Repayment\Delta L2_{i,t} = \widetilde{\Psi}_{i,t} \cdot L2_{i,t} \tag{11}$$

This statistical distribution implies an average loan outstanding time of $(\psi_L + \psi_P + \psi_U)/3$ and a modal loan outstanding time of ψ_P. Since banks only lend to own customers, this mechanism implies simple reverse lending as both $A2_{i,t}$ and $L2_{i,t}$ are reduced by $Repayment\Delta L2_{i,t}$ in the bank i balance sheet, where $L2_{i,t}$ is the existing loan portfolio of that bank. This mechanism treats the real economy as a whole, without tracking individual customers and then individual loans granted to them. In principle, each loan has its terms and conditions, including its own duration and repayment profile. This involves that, at each period of time, each bank is confronted with a portfolio of loans of different durations and repayment profiles. To capture this feature without tracking each loan, we move from a universal repayment ratio for every bank as in Xiong et al. (2017) to a stochastic one for each bank. Its statistical distribution denotes the ongoing customer credit conditions in real economy. A further extension of the model may consider here stylised facts from empirical evidence on business cycles (Kollintzas et al., 2011).

The model is calibrated to avoid customers default on their loans, implying that $L2_{i,t} \geq \Delta L2_{i,t}, \forall i,t$ (as in Equation 11 above). A further extension may consider an additional set of minimal institutions to feature customer default resolution arrangements (Goodhart et al., 2016).

2.3.2 Customer loan creation

After being repaid for previous loans, banks seek to grant new loans to their customers. The model denotes two distinctive lending strategies, namely money multiplication and fractional reserve lending.

Lending Behaviour 1: Bank money multiplication lending mechanism

Based on the target reserve ratio $\gamma_{i,t}^{TR}$ and the existing "total reserve holding" $\sum A*_{i,t}$, the maximum of total credit that each bank can grant is:

$$\gamma_{i,t}^{TR} = \frac{\sum A*_{i,t}}{\text{Maximum Lending}} \quad \Rightarrow \quad \text{Maximum Lending} = \frac{\sum A*_{i,t}}{\gamma_{i,t}^{TR}} \tag{12}$$

The existing total deposit being $\{L1+L2+L3\}_{i,t}$, each bank wishes to lend a multiple of "total reserve base" to keep new and existing loans below the maximum level, so that

$$\Delta A2_{i,t+1} \leq \frac{\sum A*_{i,t}}{\gamma_{i,t}^{TR}} - \{L1+L2+L3\}_{i,t} \tag{13}$$

with $\Delta A2 = \Delta L2$ by construction, if the potential lending offer is actually granted. If so, $A2$ and $L2$ will be updated symmetrically by the granted amount.

Therefore, the general formula of target lending under money multiplication is:

$$Potential \Delta A2_{i,t+1} = Max \left\{ 0 \ , \ \frac{\sum A*_{i,t}}{\gamma_{i,t}^{TR}} - (L1_{i,t} + L2_{i,t} + L3_{i,t}) \right\} \tag{14}$$

This formula implies that banks wish to maintain an ongoing safety net proportional to their loan outstanding $\{L1 + L2 + L3\}_{i,t}$. This restrictive condition may be relaxed by assuming $\{L1 + L2\}_{i,t}$, making interbank credit free from reserve corporate targeting or regulatory restrictions.

The target reserve parameter $\gamma^{TR}_{i,t}$ captures the bank treasury management policy which aims to maintain an ongoing safety net between cash inflows and holdings, and cash outflows and obligations. This target may include the minimum reserve ratio required by banking law and regulation (γ^{RR}), the latter being a threshold that is universal across banks, and may evolve over time and circumstances.

Various definitions of reserve base $\sum A*_{i,t}$ involve featuring notions of the ultimate means of payment and settlement. When A1 only is retained, a narrow monetary system is defined that restricts money functions to currency. When A1 and A3 are jointly retained, a broader monetary system enables banks to settle interbank payments through mutual credit admittances over time and circumstances. When A2 is introduced, a mechanism of loan securitisation is in place, enabling banks to increase their liquidity (defined as held reserve base) through refinancing on and securitisation of their asset holdings. In the rest of this article, we maintain a broad definition of reserve base including A1 and A3 (broad monetary system).

The above equation compares with the textbook representation for fractional reserve lending of loanable funds as follows:

<u>Lending Behaviour 2:</u> Fractional reserve under loanable funds constraint

Based on current amounts of the bank reserve base ($\sum A*_{i,t}$) and total deposit $\{L1+L2+L3\}_{i,t}$, individual banks calculate their own target (required) reserves $TR_{i,t}$ (i.e.: the target reserve to deal with potential deposit withdrawals):

$$TR_{i,t} = \gamma^{TR}_{i,t} \times (L1_{i,t} + L2_{i,t} + L3_{i,t}) \tag{15}$$

where $\gamma^{TR}_{i,t}$ is the target reserve ratio for bank i at time period t.

Each bank wishes to lend the share of total currently held reserve base to customers as new retail loans ($\Delta A2_{i,t+1}$) above the following target reserve threshold:

$$\Delta A2_{i,t+1} = \sum A*_{i,t} - TR_{i,t} \tag{16}$$

Therefore the general formula of target lending is:

$$Potential\Delta A2_{i,t+1} = Max\left\{ \ 0 \ , \quad \sum A{*}_{i,t} - \gamma_{i,t}^{TR} \cdot (L1_{i,t} + L2_{i,t} + L3_{i,t}) \ \right\} \tag{17}$$

In particular, the banking theory as pure intermediation of loanable funds imposes that only A1 is included in the reserve base $\sum A{*}_{i,t}$.

2.3.3 Bank credit realisation

Both lending strategies denote the ongoing bank potential offer of loans to customers at time period $h \geq t$. Banks potential offer of loans is satisfied according to the following aggregate absorption function by customers as a whole.

Hence, the actual granted loan is:

$$Actual\Delta A2_{i,t+1} = \widetilde{\Theta}_{i,t} \cdot Potential\Delta A2_{i,t+1} \tag{18}$$

where the proportion of potential lending $\widetilde{\Theta}_{i,t}$ is generated randomly from a triangular distribution (with the following lower, peak, and upper parameter):

$$\widetilde{\Theta}_{i,t}(\theta_L, \theta_P, \theta_U) \sim Triangular(\theta_L, \theta_P, \theta_U) \tag{19}$$

This statistical distribution implies an average loan absorption of $(\theta_L + \theta_P + \theta_U)/3$ and a modal loan absorption of θ_P at each period. These parameters capture ongoing customer credit conditions in bank lending activity over time and circumstances. For the sake of simplicity and without generality loss, we treat customers as a whole, disregarding individual customer patterns of bank loan granted, spent and repaid. A further extension may introduce a set of minimal institutions to design and implement real economy uses and fate of bank credit money.

Once each bank i gets its actual share of granted loans, it allocates them to its customers j, increasing simultaneously both bank loan asset portfolio ($A2_{j,h}$) and bank customer deposits ($L2_{j,h}$).

2.4 Model Module 3: Interbank settlement and credit system

Both payments settlement (module 1) over time periods t, and bank credit creation and destruction (module 2) over time periods h reshape bank outstanding asset holdings and liability obligations throughout time and space. This ongoing dynamic requires the bank treasury department to manage the bank financial process to rebalance cash (and cash equivalents) outflows and inflows, seeking to maintain ongoing bank capacity to settle obligations when they become due in time and amount. As for banks hold reserves to settle payments and meet reserve requirements (Fullwiler, 2008). Generally speaking, this ongoing rebalancing activity is performed through interbank borrowing and lending. When a bank lends to another bank, bank balance sheet simultaneously expands with the loan (an asset to the bank) and the deposit (a liability to the bank), both in the name of the other bank, while the bank promises to make the borrowing bank deposit redeemable in cash or cash equivalents (that is, whatever asset $A*$ is included in the reserve base definition $\sum A*$).

The following modeling strategy focuses on outstanding amounts of reserve need and excess, and the matching mechanism that enables potential borrowers (banks with reserve need) to meet potential lenders (banks with reserve excess). For the sake of simplicity and without generality loss, we neglect the impact of interbank interest rates (including margins) in this matching process. Empirical evidence seems to suggest that interbank credit networks rely on longstanding partnership and are quite unresponsive to counterparty risk in normal times (Finger and Lux, 2014). An extension of the model may include further stylised facts concerning interbank credit conditions and circumstances.

2.4.1 Interbank credit repayment system

Before seeking for new interbank lending and borrowing, all the banks repay their outstanding loans $L3$ that have become due in period t according to the following steps:

Step 1: Each bank records its outstanding interbank lending and borrowing over time, so every loan has one-to-one match between a lender and a borrower at a particular time t;

Step 2: At each time period, some randomly selected loans come to be repaid (selected from all outstanding loans through all historical periods), depending on the interbank repayment likelihood parameter $\omega_{i,t}$;

Step 3: The control parameter $\omega_{i,t}$ for each bank i at time period t denotes the likelihood of repayment and may vary over time and circumstances;

Step 4: The repayment is settled by the repaying bank through a proportional transfer of its reserve base components $A*$: for the lender, it decreases its interbank lending item $A3$ and increases its reserve base $A*$; for the borrower, it decreases its interbank borrowing item $L3$ and decreases its reserve base components $A*$;

Step 5: After interbank loan repayment, each bank updates its record of outstanding interbank lending and borrowing.

This simple repayment mechanism is sufficient to denote interbank credit dynamics. A further extension of the model may transform this mechanism in a more sophisticated treasury management function by each bank, and more sophisticated institutional arrangements to frame this management over time and circumstances.

The model implements interbank repayment as follows.

A 3-dimension matrix $M_{B\times B\times T}$ records all outstanding interbank loans (generated through customers' bank credit wire transfer and credit coordination in interbank networking). An outstanding loan is recorded as $m_{u\to v,t} > 0, \forall m \in M_{B\times B\times T}$, otherwise if $m_{u\to v,t} = 0$ loan is absent). At each time, another random 3-dimension matrix $\widetilde{D}_{B\times B\times T}$ is generated where each element $\tilde{d}_{u,v,t}$ is drawn from a uniform distribution $\sim U(0,1)$.

The repayment that triggers threshold in the repayment decision matrix $\widetilde{D}_{B\times B\times T}$ is fixed as follows:

$$\widetilde{d}_{u,v,t} > \omega_{u,t}, \quad \forall (u,v) \in \{m_{u\to v,t} > 0\} \tag{20}$$

(where $\omega_{u,t}$ parameter controls for interbank repayment probability, i.e. a higher $\omega_{u,t}$ means that interbank loans are repaid more slowly implying a longer duration on average, and (u,v) identifies a pair of lender-borrower.)

When the repayment is triggered, bank u repays interbank loan $m_{u\to v,t}$ where $\tilde{d}_{u,v,t} > \omega_{u,t}$, therefore $m_{u\to v,t}$ becomes zero, and the repayment is paid back to the previous lending bank v adding to its reserve base $\sum A*_{i,t}$ in proportion to reserve base components of repaying bank u. Borrower reserve accounts $A*$ decrease and may become zero for A1 and negative for other $A*$ because of this repayment. Indeed the repaying bank may seek to recover from this exposure through further inter-bank borrowing.

The balance sheet items ($A3/L3/A*$) are updated as follows:

- Once a pair of lender-borrower (u,v) is selected to repay the outstanding loan $m_{u\to v,\tau}$, the lender u's $A3_{u,t}$ and the borrower v's $L3_{v,t}$ at the current period are reduced by each $m_{u\to v,\tau}, \forall \tau \in \{1...t\}$.
- Each pair (u,v,τ) also identifies the weights of different reserve base component at time τ as $A*_{i,\tau} / \sum A*_{i,\tau}$, so the lender u's each reserve base component $A*_{u,t}$ is increased, while the borrower v's each reserve base component $A*_{v,t}$ is reduced in proportion to reserve components at current period levels.
- This process is repeated for all selected outstanding loans $m_{u,v,\tau}, \forall u, v, \tau$.

After interbank repayment settlements, banks with outstanding excess reserve holdings may seek to lend, while banks with outstanding reserve must seek to borrow. In this context, a minimal reserve requirement implies a balance threshold higher than zero to distinguish between potential lenders and borrowers.

2.4.2 Interbank credit pooling system

This section introduces the dynamic interactions of interbank credit coordination. Both the completeness and perfection of this pooling system is managed by an interbank credit control parameter $\phi \in [0, 1]$. This parameter describes interbank credit conditions and especially points to counterparty risk in bilateral and multilateral transactions within bank networks. In particular, with $\phi = 0$ the system works under complete and perfect pooling, while with $\phi = 1$ the system does not experience any interbank credit. A system is complete when all banks can potentially become borrowers and lenders. A system is perfect when all banks do actually become either borrowers or lenders. In section 4, simulation analysis will comparatively assess the system working against different levels of incomplete and imperfect coordination modes, inferring systemic implications of interbank coordination for financial stability and resilience. The inter-bank coordination quality parameter $\phi_{i,t}$ may be settled at different values across banks i and time periods t. For the sake of simplicity, our simulation analysis shall denote it through one universal value for all i, t.

Therefore, our interbank credit pooling mechanism enables controlling how potential lenders and borrowers match over time and circumstances captured by the parameter space. In particular, it may occur that some potential lenders cannot fully lend since borrowers are not found. Viceversa, some potential borrowers may find insufficient lending to satisfy their reserve need. When a potential lender cannot find sufficient borrowing requests, its reserve surplus remains unexploited. Even the central bank does not absorb those excess reserves. When a potential borrower cannot find sufficient lending offers, it shall have recourse to the central bank guarantee, in order to continue operating through the next period.

Interbank credit coordination mechanism is implemented as follows:

Calculating reserve situation: Based on its individual bank target reserve ratio $\gamma_{i,t}^{TR}$ and its own current reserve base level ($\sum A*_{i,t}$), each bank identifies its reserve surplus (denoting a potential lender) or shortage (denoting a potential borrower).

The current reserve ratio of a bank i (all balance sheet items being updated up to this step) is:

$$\gamma_{i,t}^{CR} = \frac{\sum A*_{i,t}}{L1_{i,t} + L2_{i,t} + L3_{i,t}} \tag{21}$$

The bank excess reserve (surplus) when $\gamma_{i,t}^{CR} > \gamma_{i,t}^{TR}$ is:

$$ER_{i,t} = (\gamma_{i,t}^{CR} - \gamma_{i,t}^{TR}) \cdot (L1_{i,t} + L2_{i,t} + L3_{i,t}) \tag{22}$$

The bank reserve need (shortage) when $\gamma_{i,t}^{CR} < \gamma_{i,t}^{TR}$ is:

$$RN_{i,t} = (\gamma_{i,t}^{TR} - \gamma_{i,t}^{CR}) \cdot (L1_{i,t} + L2_{i,t} + L3_{i,t}) \tag{23}$$

Calculating weights of reserve bases: since the balance sheet comprises different reserve base components $A*_{i,t} \in \{A1_{i,t}, A2_{i,t}, A3_{i,t}\}$ which may be used for interbank settlement proportionally to their relative weight in $\sum A*_{i,t}$, we compute and record the share of each reserve base component in the total reserve for each bank. When issuing or repaying the interbank loan, the reserve base components will be updated according to these weight:

$$Weight_{A*_{i,t}} = \frac{A*_{i,t}}{\sum A*_{i,t}} \tag{24}$$

Generating a potential lender-borrower matrix: All banks are now separated into two groups (i.e. lenders and borrowers). The system forms a matrix $M_{B\times B}$ (B being the total number of banks), lending banks being marked as 1 into the rows, and borrowing banks being marked as 1 into the columns. When a lending bank finds a borrowing bank, their cells in the matrix have both column and row as 1. Hence, this matrix defines all combinations of potential lenders and borrowers. When a lending bank l matches a borrowing bank b, then the element $m_{l\to b} = 1, m \in M_{B\times B}$, defining a pair (l, b). A bank with excess reserve is a potential lender for all borrowers (who need reserve), and vice-versa. Therefore,

$$m_{l\to b} = 1, \quad \forall l \in B\{\gamma_{i,t}^{CR} > \gamma_{i,t}^{TR}\} \cap \forall b \in B\{\gamma_{i,t}^{CR} < \gamma_{i,t}^{TR}\} \tag{25}$$

Generating an actual lender-borrower matrix: Another $B \times B$ matrix is used to define the actual pair of lender-borrower. The system creates a random probability selection matrix $\widetilde{M}_{B\times B}^{prob}$, whose element $\tilde{m}_{l,b}^{p}$ may be generated by "exogenous random matching".

This approach draws the actual matching matrix elements from uniform distribution as follows:

$$\tilde{m}_{l,b}^{p} \sim U(0,1) \tag{26}$$

Comparing with Delli Gatti et al. (2010), our model has few differences: (1) our model extends the loan repayment duration to multiple periods (via a stochastic loan repayment ratio $\omega_{i,t}$); (2) our model extends to multi-lenders with multi-borrowers where each lender has a limited funding; (3) they analyze the impact of lending (revenue: interest, or loss: bad debt) on bank profit and loss statement, while we focus on the impact of loan transactions on bank balance sheet dynamics.

Having generated all probabilities for all potential pairs of lender-borrower (l, b), we select those pairs whose probabilities are larger than a threshold to form actual subsets of interbank networks:

$$\tilde{m}^p_{l,b} > \phi_t, \quad \text{with } \phi_t \in [0, 1] \tag{27}$$

This threshold parameter ϕ_t controls for the degree of imperfect pooling (i.e.: if $\phi_t = 0$, then the network realises perfect pooling). This design enables selecting multi-lenders with limited funding, contrary to Delli Gatti et al. (2010) which introduce only one lender with unlimited funding available.

Allocating reserve within subsets of interbank networks: The actual selection matrix may contain either borrowers (lenders) who could not find lenders (borrowers), or borrowers (lenders) who have one or more lenders (borrowers). Each borrower decides to borrow in proportion to its reserve shortage from the group of its actual lenders based on those lenders' total excess reserve. Borrowers request the needed amount of reserve from their actual lenders. Each lender forms a subgroup between itself and its actual borrowers. This means that borrowers and lenders form subsets of interbank credit networks where banks coordinate their reserve need and excess for the period t being. Since interbank loans may last for some periods, this makes interbank credit networks evolving over time and circumstances captured by the parameter space.

Updating bank balance sheet items: If a pair of lender-borrower (l, b) performs interbank credit for an amount $\Delta A3_{l \to b,t} = \Delta L3_{l \to b,t}$, then the lender's $A3_{l,t}$ and borrower's $L3_{b,t}$ are increased by this amount. At the same time, the settled amount of reserves $A*$ is moved from the lender's to the borrower's balance sheet. This operation implies interbank settlement on a gross basis and is repeated for each paired transaction. Borrowers and lenders constitute interbank pooling networks.

Recording interbank loans in the repayment matrix: Actual new interbank loan transactions at this period t between lenders and borrowers are recorded in the 3-Dimension matrix $M_{B \times B \times T}$, together with all the other outstanding interbank credits and debts. If the interbank reserve surplus is not fully employed within a subgroup, the lenders leave the remaining amount unexploited. Viceversa, if the interbank loan need is not fully satisfied within a subgroup, the borrowers ask the central bank for overdraft assistance.

2.5 Central bank as guarantor of last resort

In some circumstances, the model dynamic makes possible that, after interbank credit coordination, one bank remains exposed, that is, it remains unable to match its reserve base targets and obligations in that time period t.

In this situation, the model introduces a non-cash central bank facility that provides a guarantee of last resort, enabling the exposed bank to roll over its overdraft obligations until the next period $t+1$. For the sake of simplicity, this facility is non-cash based, that is, it does not enter the reserve base dotation of the exposed bank, which must pay a punitive guarantee fee on this contingent liability $A5_{i,t}$ outstanding. This modeling strategy is consistent with overdraft facilities provided by major central banks (Fullwiler, 2008). This modelling strategy helps focusing the model dynamic on the direct effect of interbank credit that is under examination in this article. Central bank exposure provides a signal for financial instability and fragility generated by both bank excess behaviours and interbank lacks of coordination. A further extension of the model may include a set of minimal institutions to design and implement central bank monetary interventions and monetary financial institution defaults.

If a bank remains in reserve shortage after interbank credit coordination, that is, $\sum A*$ is less than target reserve $TR_{i,t}$, the central bank provides a guarantee $L5_{i,t}$ to complete the level of reserves with:

$$A5_{i,t} = L5_{i,t}$$

Therefore:

$$\sum A*_{i,t} + A5_{i,t} = TR_{i,t} \tag{28}$$

The assisted bank pays an overdraft guarantee fee on the central bank assistance, as follows:

$$\pi_{i,t} = \pi_{i,t-1} - r_{i,t}^{L5} \cdot L5_{i,t} \tag{29}$$

where $r_{i,t}^{L5}$ is equal to the interbank rate $r_{i,t}^{L3}$ plus a punitive spread.

This assistance from the central bank is fully removed at the beginning of the next period $t+1$ as follows:

$$\Delta A5_{i,t+1} = \Delta L5_{i,t+1} = -L5_{i,t} \tag{30}$$

Therefore, the total outstanding position $L5$ taken by the central bank on the whole banking system at time t is updated as follows:

$$L5_{t+1} = L5_t - \sum_i L5_{i,t-1} + \sum_i \Delta L5_{i,t} \tag{31}$$

2.6 Bank Equity dynamics

Bank equity was initialized by non-cash provision equally distributed across banks. We further model equity dynamics period through period. Following Xu et al. (2016), fee and interest rates of reference fluctuate according to exogenous stochastic distributions. A further extension of the model may include a set of minimal institutions to design and implement interdependency between these rates and underlying banking and financial conditions and circumstances.

Once bank balance sheets have been updated by all the four steps (payments settlement; bank credit creation and destruction; interbank settlement and credit; central bank guarantee), each bank accrues non-cash movements to its income statement as follows:

◇ Concerning bank lending department with customers:

- Borrowing interest rates paid to customers over outstanding currency deposit $L1$
- Management fees as expense to customers over held currency deposits $A1$
- Borrowing interest rates paid to customers over outstanding currency deposit $L2$
- Lending interest charges as revenues from customers over outstanding loans $A2$

◇ Concerning interbank lending and borrowing:

- Interbank lending interest charges as revenues from borrowing banks over outstanding interbank credits $A3$. Conversely, the same amounts become expenses for borrowing banks.
- Interbank borrowing interest charges as expenses to lending banks over outstanding loans $L3$. Conversely, the same amounts become revenues of lending banks.

◇ Guarantee fees as expenses incurred by the guaranteed bank over temporary central bank assistance $L5$

Bank equity is updated as follows:

$$L4_{i,t} = A4_{i,t} = L4_{i,t-1} + \pi_{i,t} \tag{32}$$

where profit $\pi_{i,t}$ is the sum of all these movements as follows:

$$\pi_{i,t} = (r_{i,t}^{A1} A1_{i,t} + r_{i,t}^{A2} A2_{i,t} + r_{i,t}^{A3} A3_{i,t}) - (r_{i,t}^{L1} L1_{i,t} + r_{i,t}^{L2} L2_{i,t} + r_{i,t}^{L3} L3_{i,t} + r_{i,t}^{L5} L5_{i,t}) \tag{33}$$

where $r_{i,t}^{A3}$ and $r_{i,t}^{L3}$ are equal for each pair between lender and borrower.

As bank balance sheet amounts evolve according to their own movements over time and circumstances, this equity dynamic enables to capture ongoing impact of various bank activities on bank profits and losses. For the sake of simplicity, this dynamics is non-cash based, that is, it does not enter the bank reserve base donation period through period and it is not distributed to management and shareholders. This modelling strategy helps focusing the model dynamic on the direct effect of interbank credit that is under examination in this article. Bank equity dynamic provides a signal for financial resilience, showing the ongoing capacity of each bank and the banking system as a whole to face possible credit losses. A further extension of the model may include a set of minimal institutions to design and implement cash equity transactions, including transactions with shareholders and bank default resolutions.

The Table 2 summarizes key parameters, and their benchmark values and features. Figure 1 visualises the model structure and dynamics. The model dynamics is driven by several stochastic processes for payments flows, bank costumer loans repayment and generation, and interbank credit repayment and granting. In particular, this baseline scenario calibration scopes out bankruptcy of customers and banks, in order to focus our simulation results on the direct effects of interbank coordination over time and circumstances. For the same reason, the total base money provided by the central bank $A1$ is kept constant throughout all the periods and replications.

Table 2: Summary of parameters and values in the model

Parameter	Description	Benchmark	Variation	Baseline Calibration (Section 4)
T	Total time periods		Fixed	50
B	Total number of banks		Fixed	10
C	Total number of customers		Fixed	1000
$A1_0$	Total base money	1×10^9	Fixed	1×10^9
$A4_0$	Total capital of all banks	1×10^8	Fixed	1×10^8
$r_{i,t}^{A1}$	Interest rate of asset A1	0.01	[0.005, 0.015]	$\sim Triangular(0.005, 0.01, 0.015)$
$r_{i,t}^{A2}$	Interest rate of asset A2	0.03	[0.02, 0.04]	$\sim Triangular(0.02, 0.03, 0.04)$
$r_{i,t}^{A3}$	Interest rate of asset A3	0.015	[0.005, 0.025]	$\sim Triangular(0.005, 0.015, 0.025)$
$r_{i,t}^{L1}$	Interest rate of liability L1	0.01	[0.005, 0.015]	$\sim Triangular(0.005, 0.01, 0.015)$
$r_{i,t}^{L2}$	Interest rate of liability L2	0.01	[0.005, 0.015]	$\sim Triangular(0.005, 0.01, 0.015)$
$r_{i,t}^{L3}$	Interest rate of liability L3	0.015	[0.005, 0.025]	$\sim Triangular(0.005, 0.015, 0.025)$
$r_{i,t}^{L5}$	Interest rate of liability L5	$r_{i,t}^{L3} + 0.03$	[0.035, 0.055]	$r_{i,t}^{L3} + 0.03$
γ^{RR}	Bank required reserve ratio	0.1	Fixed	0.1
$\gamma_{i,t}^{TR}$	Bank target reserve ratio	$\gamma^{RR} + \tilde{z}$	Stochastic	γ^{RR}
α	Partner selection	not used	Fixed	n/a in "Exogenous matching"
λ	Partner selection	not used	Fixed	n/a in "Exogenous matching"
$\phi_{i,t}$	Interbank credit pooling quality	0	[0,1]	0/0.4/0.8
$\theta_L, \theta_P, \theta_U$	Actual customer loan creation	(0,0.5,1)	[0,1]	$\sim Triangular(0, 0.8, 1)$
ψ_L, ψ_P, ψ_U	Customer loan repayment	(0,0.5,1)	[0,1]	$\sim Triangular(0, 0.5, 1)$
$\omega_{i,t}$	Interbank loan repayment	(0,0.5,1)	[0,1]	0.5
ξ_1	Scale of customers' cash payment	0.1	[0,1]	0.1
ξ_2	Scale of bank credit wire transfer	0.1	[0,1]	0.1

3 Interbank credit and the money generation process

Our model features the connection between money as a means of payment and bank credit generation. In particular, banks define their lending strategy in relation to their ongoing capacity to face payment settlement obligations over time and circumstances. This implies that banks watch over ongoing inflows and outflows of means of payment (cash and cash equivalents) in order to target their ongoing potential capacity to offer loans period through period. In this context, bank reserve holdings are defined through whatever bank assets $A*$ that may be used to settle payments with other banks. These assets jointly define the reserve base that the bank takes into account to decide its lending capacity through leverage, enabling its contribution to the money multiplication process. Schumpeter (1954, pp. 320) masterly denotes this process as money manufacturing. In this context, "banks are no longer said to 'lend their deposits' or 'other people's money,' but to 'create' deposits or bank notes: they appear to manufacture money rather than to increase its velocity or to act, which is a completely unrealistic idea, on behalf of their depositors."

According to textbook story of money creation under fractional reserves and available loanable funds, interbank credit is relegated to the backyard of the banking system. It may be considered as a minor mechanism that enables banks to temporarily postpone payments in order to facilitate settlement and clearing across banks, with no impact on the overall working of the banking system. Our model is capable to reproduce this narrow monetary system as a cornerstone case which occurs when the reserve base $\sum A*$ is narrowly defined as currency only, that is, $A1$. This case may be tested under both lending mechanisms (Equation 17 and 14) which feature fractional reserve and money multiplication processes. Under both mechanisms, narrow reserve definition and related management define the limits of the banking system money capacitance. Figure 2 illustrates this result.

However, the functional equivalence between currency and deposit introduces an additional source of money creation into the financial system. This source comes from the working banking system which, through interbank credit, makes itself potentially independent from base money issued by central banking. Heuristically, this may happen not only when central banking expands its reserve base definition to admit bank securities and bank credit admittances ($A3_{i,t}$) to its refinancing facilities, but also when banks keep renewing drawing facilities to each other ($L3_{i,t}$), or keep issuing credit admittances ($A3_{i,t}$) that circulate as cash equivalents for settling interbank payments over time. Figure 3 illustrates this scenario.

Under ideal conditions similar to the textbook case (Figure 3 case: left diagram), broad interbank credit mechanism involves two featuring results that contrast with received textbook story. According to the latter, interbank credit does not matter and the aggregate money creation is bound by the outstanding reserve base issued by the central bank (high powered money). In contrast, on the one hand, a banking system embedded into a broad monetary system generates an additional money aggregate made of interbank credit money which complements both bank credit money and currency money aggregates. On the other hand, such a banking system makes the potential offer of bank credit potentially unbound (Figure 3 cases: middle and right diagrams). Therefore, interbank credit can remove the inner limits of the monetary system capacitance in this configuration.

These featuring results pave the way to a better understanding of systemic implications of interbank credit for financial stability and resilience. As for interbank credit generates additional aggregate money while increasing bank leverage and exposure. It further expands bank credit capacity potentially without limits or, better, within evolving limits endogenously imposed by real economy absorption and institutional arrangements. The next section applies this model to assess the impact on financial stability and resilience by this broad banking system under conditions of incomplete and imperfect interbank credit pooling.

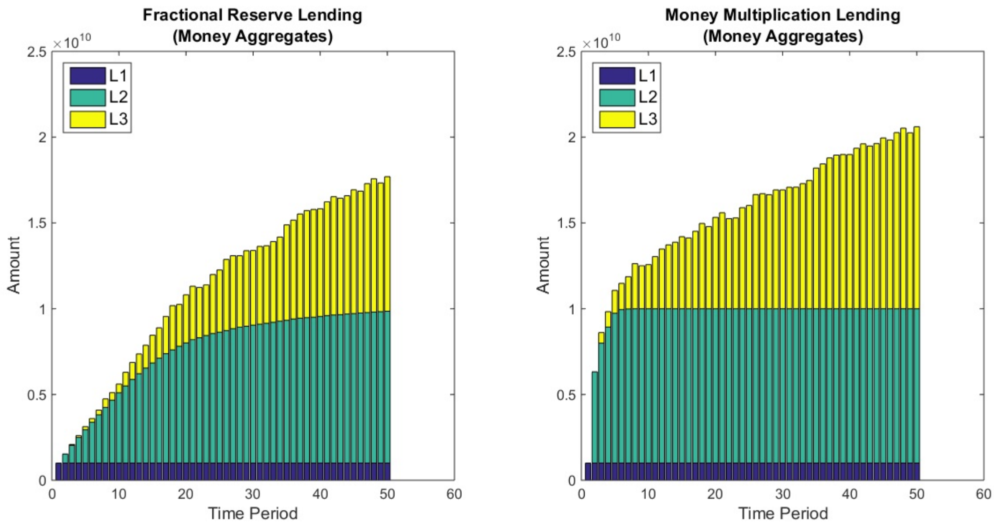

Figure 2: *Money aggregates analysis under narrow banking: both visualizations are generated, when the interbank coordination is in perfect pooling, all banks use A1 as the reserve base (i.e. narrow banking), no repayment of customer loans, the interbank loans are repaid randomly and on average repaid fully in two time periods. Other parameters follow the baseline scenario in Table 2. Left diagram shows the simulation result when all banks' lending strategy is based on the conventional rule of fractional reserve (Equation 17), while the right diagram illustrates the money multiplication lending strategy (Equation 14).*

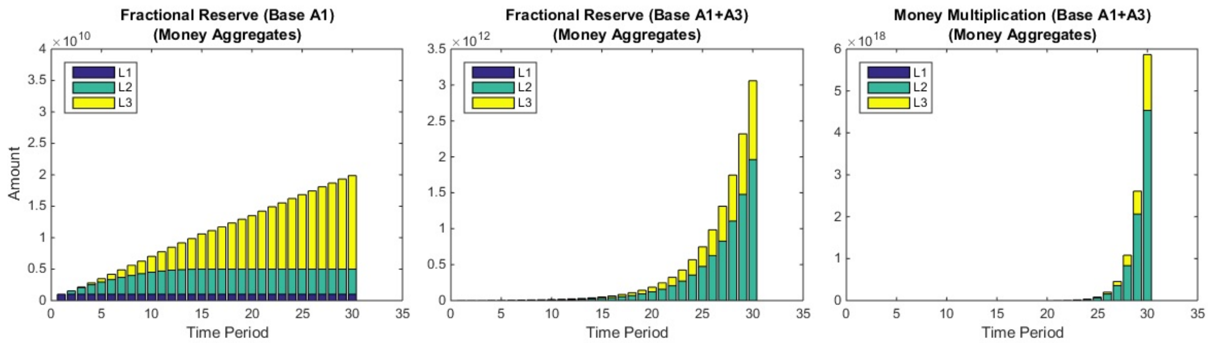

Figure 3: *Money aggregates analysis under narrow and broad banking: all three visualizations are generated, when the interbank coordination occurs under perfect pooling, no repayment of customer loans, and no repayment of interbank loans. Other parameters follow the baseline scenario in Table 2. The left graph represents the simulation result when all banks use A1 as the reserve base (i.e. narrow banking), while banks in both the middle and right graphs use $A1 + A3$ as reserve base (i.e. broad banking). Moreover, banks in both the left and middle graphs use the lending strategy of fractional reserve (Equation 17), while the right graph is based on the lending strategy of money multiplication (Equation 14).*

4 Financial stability and interbank credit coordination modes

Section 2 introduced our model of bank credit creation featured by interbank credit under the functional equivalence between currency and deposit (broad banking). Section 3 illustrated the working of the banking system in case of perfect and complete interbank credit pooling across all the monetary financial institutions (banks).

Complete and perfect pooling provides a benchmark representation against which we may comparatively assess the impact of interbank credit coordination on financial stability and resilience. This ideal coordination mode enables all the banks to access to all the others at each time period (complete pooling network), with all banks being interested in either lending to, or borrowing from each other (perfect pooling network). Therefore, the reserve base that is factually segregated between banks is completely and perfectly pooled across them, in view to assure interbank settlement and credit at each time period t.

This section 4 develops some visualizations through simulation analysis to compare results under this ideal coordination mode with two alternative modes of incomplete and imperfect pooling. One mode is featured by a smooth degree of inter-bank coordination (with $\phi = 0.4$). Another mode is featured by a distressed degree of inter-bank coordination (with $\phi = 0.8$). When inter-bank credit conditions worsen, it becomes increasingly difficult for potential borrowing banks to find counter-parties willing to lend (captured by increasing levels of inter-bank coordination quality parameter ϕ). This comparative analysis may help inferring implications of banking system dynamic for financial stability and resilience.

The following simulation analysis applies a baseline calibration that is common to each scenario (Table 2). This calibration sets the same economic and financial conditions through all time periods and all visualizations. Banks operate under the broad banking regime (the monetary base being then defined by $A1+A3$) and through the money multiplication lending strategy (Equation 14). Customer and interbank credit repayments are now activated and dynamically offset the ongoing credit creation granted to customers and other banks. By assumption, interbank credit is repaid quicker than customer credit. For the sake of simplicity, no default occurs on either credit facility. Our simulation analysis focuses on systemic outcomes under featured conditions of interbank coordination. In particular, we visualize results for four systemic outcomes under three levels of interbank credit coordination quality (labeled respectively perfect, smooth, and distressed pooling). The four systemic outcomes point to: (i) customer lending; (ii) interbank credit (lending and borrowing); (iii) central bank recourse; and (iv) bank equity and profit and loss at each period. The following analysis summarizes results from a series of 1000 replications run on the baseline calibration in Table 2.

For the sake of comparison with visualizations in section 3 (Figures 2 and 3), the money aggregates dynamics under baseline calibration is reproduced in Figure 4. Individual banks analysis (Figure 4 panel 2) shows that banks follow their own heterogeneous time patterns for each money aggregate $\{L1_{i,t}; L2_{i,t}; L3_{i,t}\}$, which sums up to generate a banking system with moderate customer loan growth over time (Figure 4 panel 1).

Concerning customer lending (Figure 5), better interbank credit coordination (perfect and smooth pooling scenarios) involves higher aggregate lending to customers. Moreover, some individual banks can also maintain larger customer loan portfolios over time in this circumstance. This result is qualified by the quite heroic assumption that real economy customers do keep absorbing bank loan offers over time without limit or default. It may be further tested by sensitivity analysis over the parameter space.

Increased customer lending does further involve an increased interdependency on the flow of payments that are performed through bank wire transfer movements across customer bank deposits $L2_{i,t}$. Concerning interbank lending (Figure 6) and borrowing (Figure 7), individual interbank credit behaves as expected to worsening interbank coordination quality (increasing level of ϕ). Worsened conditions reduce overall interbank lending both in aggregate (Figure 6 panel 1 and 2) and at the level of individual banks (Figure 6 panel 3). Therefore, borrowing banks are restrained in their access to interbank credit (Figure 7), both in aggregate (Figure 7 panel 1 and 2) and for individual amounts (Figure 7 panel 3).

Although better interbank credit conditions involve larger and more intense exposure to interbank borrowing (Figure 7), this does not generate increased recourse to central bank assistance (Figure 8). Deterioration in interbank coordination (smooth and distressed pooling scenarios) generates fragilities in individual and aggregate bank exposures. As long as interbank coordination works perfectly (perfect pooling scenario), aggregate and individual recourses to central bank assistance are immaterial and then virtually non-existent (Figure 8, perfect pooling scenario). When interbank conditions worsen, banks are increasingly forced to have recourse to central bank overdraft facility to keep their affairs ongoing. Their recourse becomes more intense in amount and more frequent in time (Figure 8 and 10), involving longer and more acute state of distress for individual banks and then the banking system as a whole. As expected, distressed pooling scenario makes the central bank recourse $L5_{i,t}$ the most frequent in time and the most intense in both aggregate and individual amounts. Moreover, the banking system needs assistance almost permanently under distressed pooling, while assistance requests occur later and sporadically under smooth pooling.

Previous analysis shows that interbank credit coordination has impact on customer loan, interbank borrowing and recourse to central bank assistance. Consequently, it shapes bank equity dynamics over time and circumstances (Figure 9). Under lower interbank coordination quality (smooth and distressed pooling scenarios), bank equity ($L4_{i,t}$) remains thinner on average and more concentrated on lower amounts (Figure 9 panel 1). Bank profits and losses (P/L) of the period $\pi_{i,t}$ (i.e. $\Delta L4_{i,t}$ through time periods) are also materially lower, due to reduced revenue from customer loans and increased expense for central bank assistance. Therefore, under lower interbank coordination quality (smooth and distressed pooling scenarios), banks are increasingly unable to accumulate equity reserves through retained earnings, in view to protect themselves against possible losses incurred in ongoing customer and interbank lending (Figure 9 panel 2). In fact, this result is qualified by the quite heroic assumption that banks do not distribute dividends to management and shareholders. It may yet hold when this distribution remains in line with realized earnings over time and circumstances.

5 Concluding remarks

Troubles in interbank credit coordination may trigger systemic crises. This happened when, since summer 2007, interbank credit did not longer work smoothly across financial institutions, eventually leading to central bank interventions and government bailouts to protect financial stability and assure financial resilience. While this crisis was accidentally triggered by rising actual and expected defaults in some bank asset categories, the origins of the global financial meltdown were found in systemic fragilities related to bank excess behaviours and the overarching dynamics of interbank credit.

Our article develops an interacting heterogeneous agent-based model of interbank credit coordination under minimal institutions, taking a systemic perspective on the relationship between bank credit, money creation and interbank credit. Specific attention is paid to the way banks perform credit creation along with interbank credit, clearing, and payment settlements.

First, our analysis explores the relationship between interbank credit coordination and aggregate money generation process. Contrary to received wisdom, interbank credit has the capacity to remove the inner limits of monetary system capacitance in some configurations. Second, a simulation analysis investigates modes of interbank credit coordination, addressing interbank dynamics impact on financial stability and resilience at individual and aggregate levels. Systemically destabilizing forces prove to be related to the working of the banking system over time, especially interbank coordination conditions and circumstances.

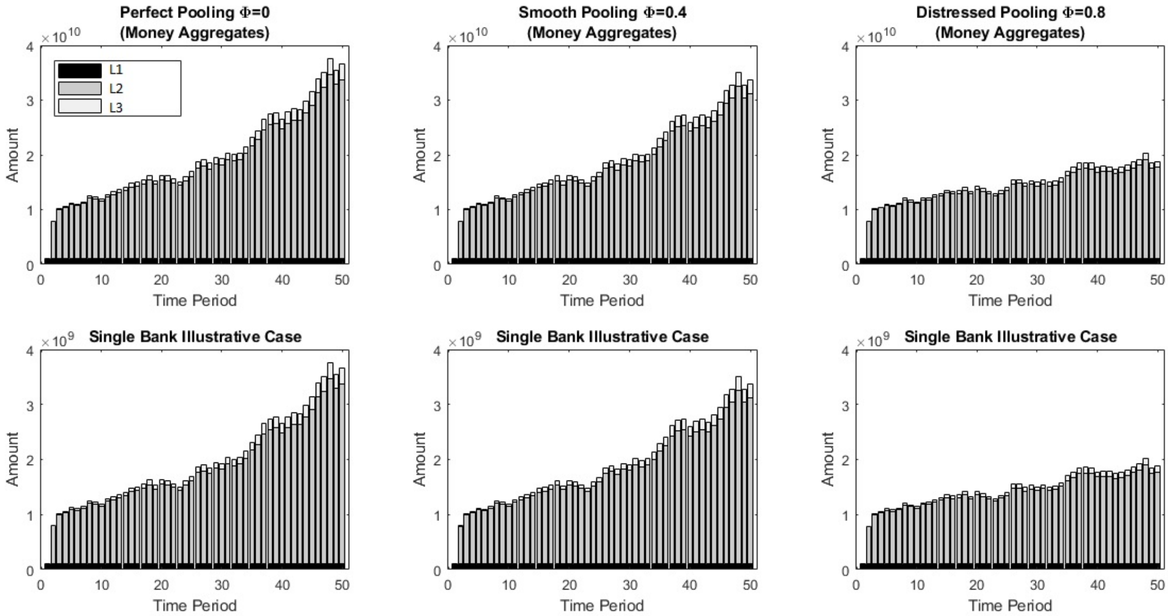

Figure 4: *Money aggregate dynamics under baseline calibration (Parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario.). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling* $\phi = 0$*, smooth pooling* $\phi = 0.4$*, and distressed pooling* $\phi = 0.8$*). Panel 1 shows the mean of total amounts of money aggregates under the three analyzed cases, and Panel 2 shows an average of a single bank illustrative case.*

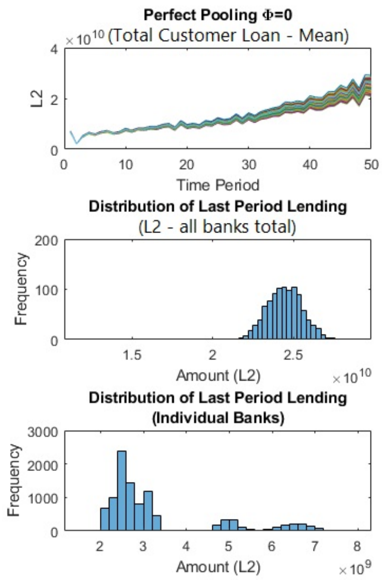

Figure 5: *Customer lending under baseline calibration (parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling $\phi = 0$, smooth pooling $\phi = 0.4$, and distressed pooling $\phi = 0.8$, three columns represent different pooling conditions). Panel 1 shows the mean of total accumulated amounts of customer loans under three analyzed cases over time, Panel 2 provides the histograms of the mean overall customer loans in the last time period, and Panel 3 provides the histograms of mean individual banks' customer loans in the last time period.*

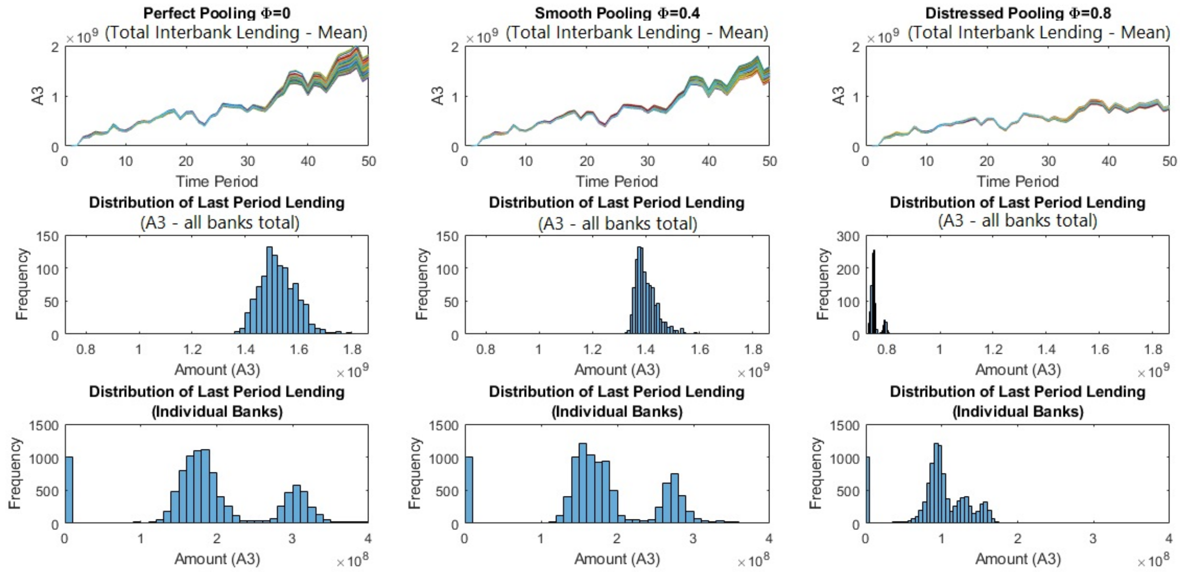

Figure 6: *Interbank lending under baseline calibration (parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling $\phi = 0$, smooth pooling $\phi = 0.4$, and distressed pooling $\phi = 0.8$, three columns represent different pooling conditions). Panel 1 shows the mean total accumulated amounts of interbank lending in the system of three analyzed cases over time, Panel 2 provides the histograms of the last time period mean overall interbank lending, and Panel 3 provides the histograms of mean individual banks' interbank lending in the last time period.*

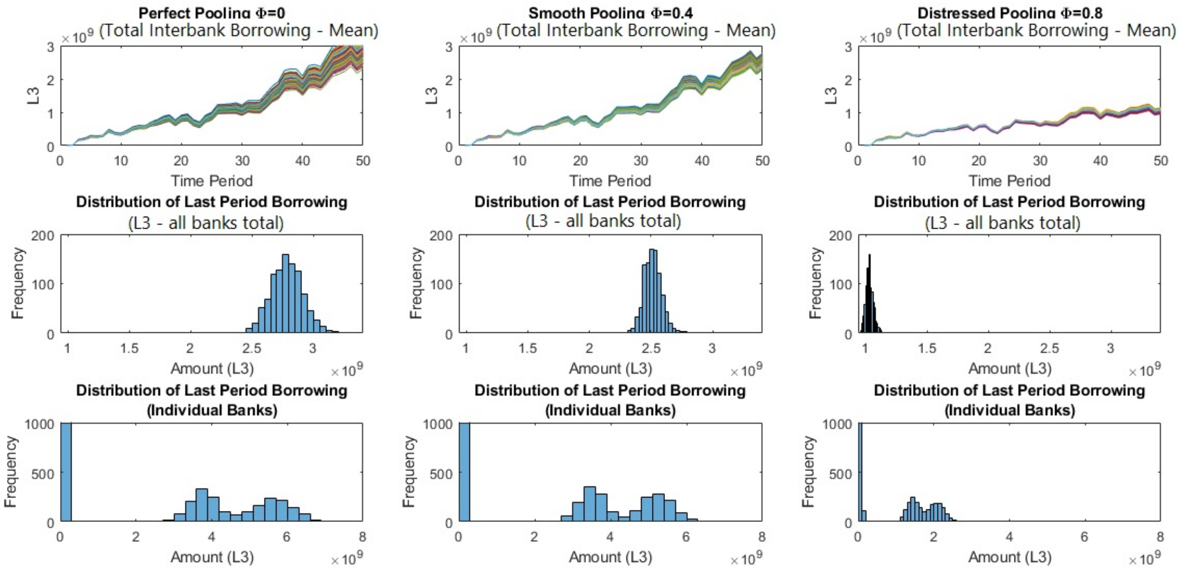

Figure 7: *Interbank borrowing under baseline calibration (parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling $\phi = 0$, smooth pooling $\phi = 0.4$, and distressed pooling $\phi = 0.8$, three columns represent different pooling conditions). Panel 1 shows the mean total accumulated amounts of interbank borrowing in the system of three analyzed cases over time, Panel 2 provides the histograms of the last time period mean overall interbank borrowing, and Panel 3 provides the histograms of mean individual banks' interbank borrowing in the last time period.*

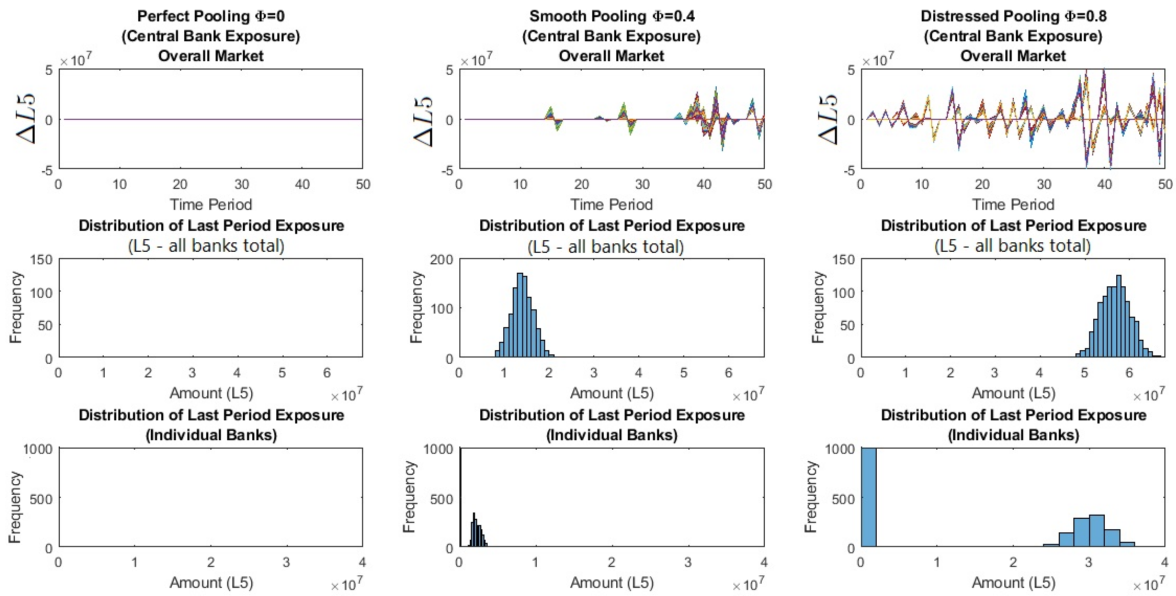

Figure 8: *Central bank assistance L5 (see Equation 31) under baseline calibration (parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling $\phi = 0$, smooth pooling $\phi = 0.4$, and distressed pooling $\phi = 0.8$, three columns represent different pooling conditions). Panel 1 shows the mean amounts of central bank assistance change $\Delta L5$ in the system of three analyzed cases over time, Panel 2 provides the histograms of mean overall central bank assistance ($\sum_i L5_i$) in the last time period, and Panel 3 provides the histograms of mean individual central bank assistance ($L5_i$) in the last time period.*

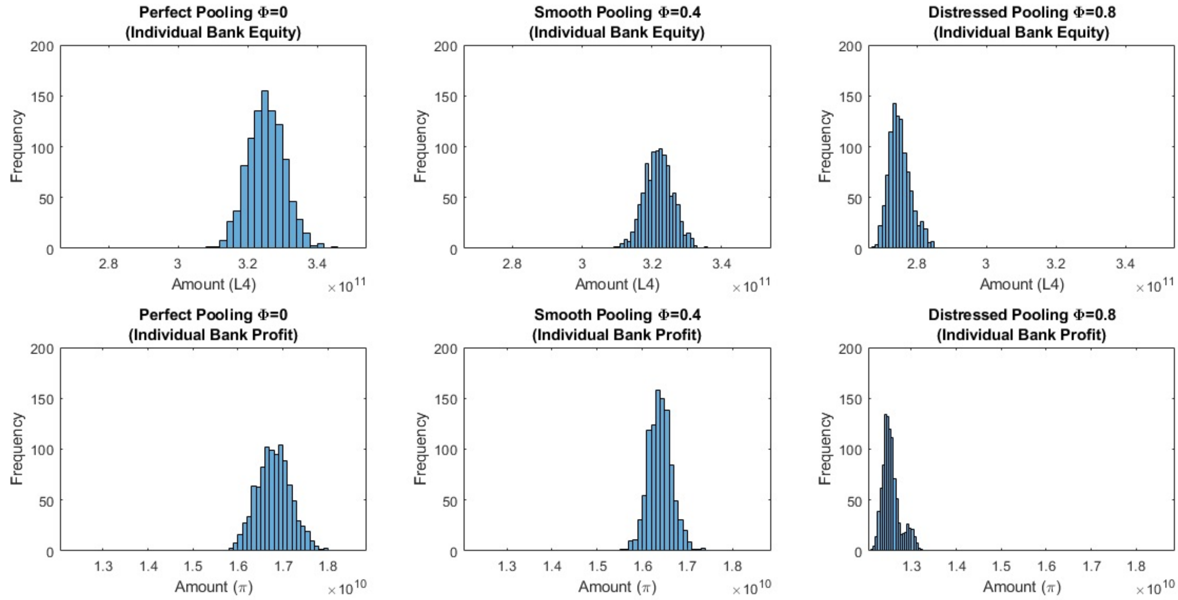

Figure 9: *Bank equity dynamics over time and circumstances under baseline calibration (parameter values are summarized in the Table 2, numerical data are extracted from 1000 replications under this baseline scenario). Three degrees of inter-bank coordination are analyzed (i.e. perfect pooling $\phi = 0$, smooth pooling $\phi = 0.4$, and distressed pooling $\phi = 0.8$, three columns represent different pooling conditions). Panel 1 shows the histograms of mean bank equity ($L4_{i,t}$) over time in the system of three analyzed cases (Equation 32), and Panel 2 provides the histograms of mean individual banks' profit or loss ($\pi_{i,t}$) in each time period (Equation 33).*

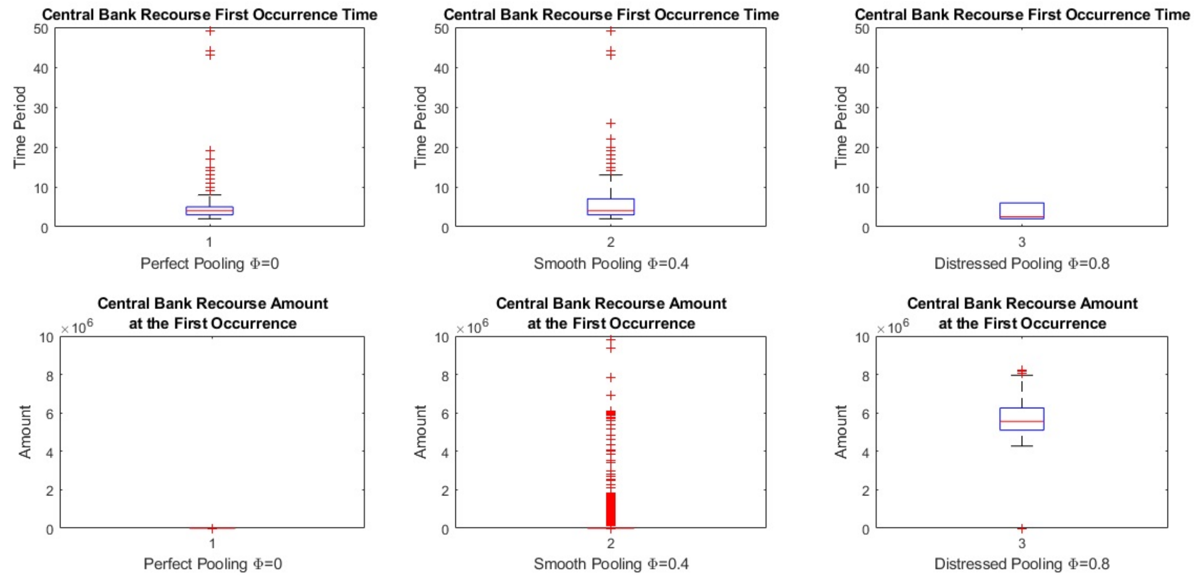

Figure 10: *Box-plot of the first time occurrence T_i for central bank guarantee intervention $L5_i$ under the various pooling conditions (Panel 1) and the amount ($L5_i, T$) of these first time occurrences (Panel 2). Numerical data are extracted from 1000 replications under the baseline scenario (Table 2).*

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