Money creation under multiple regulations in the presence of an interbank market

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Abstract

Since the recent financial crisis along with more concentration of banking supervision, we have stepped into a new regulatory regime where both liquidity and capital regulations are implemented simultaneously. Interbank lending and borrowing occur when financial institutions seek to settle and refinance their mutual positions over time and circumstances. In this paper, we study the impact of interbank liquidity trading on money creation in an agent-based banking system who is supervised by multiple regulations. According to the credit creation theory of banking, commercial banks can create both money and loans through lending. However, this bank lending process will be constrained by prudential regulations. Each regulatory instrument imposes a credit capacity which is determined by the most stringent regulation. Those banks, who are bound by liquidity regulations, may borrow liquid assets in the interbank market as long as other banks with excess liquidity have confidence in the market. A larger quantity of liquidity trading would lead to an increase in money supply provided by the banking system. We put forward an agent-based model of commercial banks each of which is described by a simplified balance sheet. The result obtained in this paper facilitates the understandings about the interaction between the interbank market and prudential regulations.

Keywords: Money supply, money creation, prudential regulation, interbank market, balance sheet approach
JEL classification: E51, G28, E47, C63

1. Introduction

Evidence from the global financial crisis of 2007-2008 has been renewing theoretical interest in understanding the role of banking, money and credit in economic and financial dynamics. Many reasons have been taken account for

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this crisis but the main culprit should be the banking system who is prone to underestimate risks and enjoys the privilege of offering credit [1, 2, 3]. Intensive credit growth usually imposes high costs not only to the financial sector but also to the economy at large [4]. Aiming to promote a more resilient and robust financial system and prevent future collapse, the Basel Committee on Banking Supervision (BCBS) has published Basel III documents and made several reforms to strengthen banks' capital and liquidity positions. On the first place, Basel III strengthens the capital supervision on banks' equity position against default risk by raising the required capital adequacy ratio (CAR), and leverage ratio (LR). While the leverage ratio is a non-risk capital requirement, which serves as a backup limit on the expansion of bank balance sheet [5, 6, 7]. On the other, Basel III introduces liquidity coverage ratio (LCR) and net stable funding ratio (NSFR) in order to improve banks' liquidity profile under stressed conditions [8, 9]. Since then, the new framework introduced with Basel III implied a shift from a unipolar approach, centered on risk-based measures of capital adequacy, towards a multi-polar one [10], with multiple regulatory constraints at play, i.e. capital ratios and liquidity ratios. In response to Haldane's calls, recent efforts can be found in analyzing how each regulatory instrument interacts with each other [11, 12, 13].

During the last decade, interbank markets have been put under the spotlight after the financial crisis [14, 15, 16]. Recently, the role of money, credit and interbank credit networks in the working of the financial system has been investigated when financial crises occur [17, 18, 19]. From a macroeconomic viewpoint, interbank rates matter especially because they play a key part of the monetary policy transmission mechanism. A profusion of efforts have been made in order to answer the question: "what are the transmission mechanisms between the banking system and the real economy"?. One of the answers is that banking crises hit real economies via the financial accelerator [20, 21]. While the other one argues that banking crises and credit supply also depend on liquidity profusion in the interbank market [22, 23, 24]. In fact, the facility through which bank can get liquidity affects their credit supply thus dampening or magnifying the financial accelerator dynamics [25, 26]. For this reason, the debate on interactions between monetary policy and macro-prudential regulations should also be focusing on the co-evolution of interbank and credit markets and their possible impact on financial instability and, more generally, on economic dynamics.

Similarly, most of the researches investigate the macroeconomic impacts of the Basel III accord, focusing on the bank's asset side (debt) as well [27, 28, 29]. In terms of the macroeconomic impacts of capital regulations, it is well demonstrated by the existing literature that bank lending would be decreased when capital related prudential requirement is tightened, especially in the short term [30, 31, 32]. This paper differs from them in the following aspects. First of all, what we are concerned about is the collective impacts of multiple regulations, including capital related regulations and liquidity related ones. From this point of view, we may find some literature attempting to figure out the impacts of liquidity regulations on bank behavior [33, 34]. In response to Haldane's call for more efforts on multi-polar regulatory regime, we consider four regulatory instruments in this paper, i.e. capital adequacy regulation, leverage regulation, liquidity coverage regulation and net stable funding regulation [10]. Second, we turn our focus to bank's liability side (money). To the best of our knowledge, we may still find some literature even if it is in a minor group, who paid attention on the changes of money supply, resulting from variations in the regulatory constraints faced by banks [35, 36, 37, 38, 39]. Among these literature, it is emphasized by Boyao Li et al. and Wanting Xiong et al. over and again that the mechanism of credit creation of banks should be regarded as the central point when analyzing the impacts of prudential regulations on money supply. In contrast, according to the conventional financial intermediary theory of banking which regards deposits solely as the sources of funds, the regulations would only generate up to indirect and secondary impacts on the lending of banks, [37, 38, 39].

The credit creation theory of banking just began to attract growing attention after the 2008 financial crisis due to the fact that the prevailing analytical framework fails to understand the role of credit for its neglect of commercial banks. In fact, it has been long argued that credit should be naturally the heart of the macroeconomic models. It has been revealed that the recent crises were almost always preceded by excessive credit booms [40, 41], and the excessive stock and rapid expansion of credit created by banks could even destroy macroeconomic stability [1, 2, 3, 42, 43]. Moreover, credit has its separate channel in stimulating the macro-economy, especially in times of stress [44, 45, 46]. In contrast to the dominant view on banks, the credit creation theory of banking argues that money is created through commercial bank lending. When a bank makes a loan to a borrower, it writes the same amount of deposits on his account, which thereby expands both sides of the bank's balance sheet. In the opposite operation, when the loans are repaid, they would then be erased from the debtor's account, and the corresponding deposits are annihilated simultaneously[47, 48, 49, 50, 51, 52]. Thanks to substantial progress in data collection and analysis, this theory has even been supported by the empirical study[48]. After being received increasing attention, the credit creation theory of banking has been applied to analyze the present monetary systems[47, 53, 54, 55, 56, 57].

Our model belongs to an expanding literature of agent-based models (ABMs) where the economy is considered as a complex system of heterogeneous agents [58, 59, 60]. In that, ABMs are particularly suited to study interbank liquidity market where heterogenous agent-specific solvency and liquidity risks affect their interactions and can possibly lead to some coordination failures. Before the Basel III accord set a liquidity constraint for banks, banks could engage in liquidity trading in the interbank market to satisfy their liquidity needs arising from these liquidity constraints. Even if there was a severe shortage of liquidity, the central bank can supply liquidity to the interbank market. Moreover, the government has to depend on fiscal policy to bail out banks in case of crisis. In this paper, we only consider the presence of interbank market when it comes to the impacts of multiple regulations on banks' money creation for the sake of simplicity. It does not mean the Central Bank invention and the government are not important, the reason for us to simplify the analysis is that this paper is just the initial step of the series of future researches. Only if we clarify the role of interbank market when discussing the multiple regulations, can we further examine the effects of central bank as well as government inventions. The rest of the paper is organized as follows. Section 2 introduces the benchmark model without interbank liquidity trading and analyze the collective impacts of multiple regulations on the aggregate money supply by deriving at the corresponding expressions of money and credit supply. Section 3 put forward the mechanism of liquidity trading and introduce the agent-based model with interbank liquidity trading. Section 4 presents the numerical calculation results and elaborates the changes resulting from the interbank liquidity trading. Section 5 draws the conclusion.

2. The benchmark model without liquidity trading

In this section, we firstly propose a benchmark model where banks do not interact with each other by liquidity trading. Then we put forward a liquidity trading mechanism of the interbank market based on the regulatory instruments of the Basel III accord. In Section 2.1, we introduce the simplified bank balance sheet. In Section 2.2, we analyze the standalone impact of prudential regulations on money supply by obtaining the expressions of money supply when each bank is under the supervision of a single regulation. In Section 2.3, we demonstrate the collective impacts of multiple regulations on money supply by deriving at the corresponding maximum money and loan supply.

2.1. The simplified bank balance sheet

In order to have a benchmark model without interbank market, we consider an agent-based model of N commercial banks in a hypothetical cashless economy, where each bank i is endowed with a simplified balance sheet, as shown in Table 1. Under the assumption that there is no interbank trading, bank i holds reserves R_i with zero risk-weight and loans L_i with risk-weight of γ as its assets while deposits D_i and equity E_i as its liabilities. According to the balance sheet consistency, the following identity should always hold,

$$R_i + L_i = D_i + E_i. \tag{1}$$

For the sake of simplicity, we introduce the ratio of equity to reserves, which is denoted by

$$e_i = \frac{E_i}{R_i}. \tag{2}$$

Table 1: The simplified balance sheet for bank i

Assets	Liabilities
Reserves (R_i)	Deposits (D_i)
Loans (L_i)	Equity (E_i)

2.2. The standalone impact of prudential regulations

2.2.1. The liquidity coverage ratio (LCR)

The LCR regulation requires each bank to hold sufficient high quality liquid assets ($HQLA_i$) that can cover its expected net cash outflows ($NCOF_i$) during a 30-calendar-day under liquidity stressed conditions. The actual liquidity coverage ratio of bank i is denoted by LCR_i and the required minimum of LCR is represented by LCR_{min}, so the restriction of LCR can be expressed as

$$LCR_i = \frac{HQLA_i}{NCOF_i} \geq LCR_{min}. \tag{3}$$

Since only reserves are considered as high quality liquid assets in the simplified balance sheet, we then have

$$HQLA_i = R_i. \tag{4}$$

In addition, according to the Basel III accord, the net cash outflows are defined as

$$NCOF_i = OF_i - \min\{IF_i, 0.75OF_i\}, \tag{5}$$

where OF_i is the expected total cash outflows of bank i, and IF_i is the expected total cash inflows within 30-day horizon of bank i. OF_i is calculated by multiplying the nominal value of liabilities by the rates at which they are expected to run off in the concerned stressed period. In our model, the run-off rate of deposits is denoted by μ, and one unit of time is set to be 30 days, so we have

$$OF_i = \mu D_i. \tag{6}$$

On the other hand, IF_i is computed according to the total amount of repayment (denoted by RP_i) with a discount of 50% due to the hypothesis of stressed scenario, which is given by

$$IF_i = 0.5RP_i. \tag{7}$$

Suppose RP_i is proportional to the outstanding loans with a rate of λ, then IF_i can be rewritten as

$$IF_i = 0.5\lambda L_i. \tag{8}$$

According to the consistency of balance sheet given by Equation 1, we can derive at the maximum money supply of bank i under LCR regulation ($D_{i,max}^{LCR}$) as follows,

$$D_{i,max}^{LCR} = \begin{cases} \frac{4}{\mu \cdot LCR_{min}} \cdot R_i, & \lambda \geq \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}; \\ \frac{(1+0.5\lambda(e_i-1)LCR_{min})}{(\mu-0.5\lambda)LCR_{min}} \cdot R_i, & \lambda < \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}. \end{cases} \tag{9}$$

The ratio of deposits to reserves of bank i can be expressed as

$$m_i^{LCR} = \begin{cases} \frac{4}{\mu \cdot LCR_{min}}, & \lambda \geq \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}; \\ \frac{(1+0.5\lambda(e_i-1)LCR_{min})}{(\mu-0.5\lambda)LCR_{min}}, & \lambda < \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}. \end{cases} \tag{10}$$

Correspondingly, we can also derive at the maximum amount of outstanding loans that bank i can issue under LCR regulation, denoted by $L_{i,max}^{LCR}$, which is given by

$$L_{i,max}^{LCR} = \begin{cases} (\frac{4}{\mu \cdot LCR_{min}} + e_i - 1) \cdot R_i, & \lambda \geq \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}; \\ (\frac{1+0.5\lambda(e_i-1)LCR_{min}}{(\mu-0.5\lambda)LCR_{min}} + e_i - 1) \cdot R_i, & \lambda < \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}. \end{cases} \tag{11}$$

From Equation 9, we can easily find that $(D_{i,max}^{LCR})$ is negatively associated with LCR_{min}, implying that money supply would shrink under a stricter requirement of liquidity coverage ratio. And it is also obvious that equity to reserve ratio e only takes effect on money supply when $\lambda < \frac{1.5\mu}{1+0.25\mu(e_i-1)LCR_{min}}$, under which circumstance $(D_{i,max}^{LCR})$ is an increasing function of e.

2.2.2. The net stable funding ratio (NSFR)

While both LCR and NSFR regulations protect banks against liquidity risks, the latter aims to reduce funding risk within a longer time horizon. The $NSFR_i$ is the ratio of the amount of available stable funding ASF_i to the required amount of stable funding RSF_i of bank i. ASF is measured as the weighted sum of the bank's sources of funds which differ in terms of stability during stressed times. In principle, higher weight is assigned to more stable funding source. Therefore, assuming that the weights in ASF for bank equity and deposits are calculated by 100% and $\beta(\beta \in (0, 1])$ respectively, we have

$$ASF_i = E_i + \beta D_i. \tag{12}$$

Similarly, RSF is measured as the weighted sum of the bank's uses of funds, which reflects the expected exposure of asset loss[1]. Each type of assets is assigned with an RSF weight, while higher weights are given to assets with higher liquidity risk. Suppose the RSF weight is $\epsilon(\epsilon \in (0, 1])$ for loans and 0% for reserves. The expression for RSF_i of bank i is then given by

$$RSF_i = 0 * R_i + \epsilon * L_i = \epsilon * L_i. \tag{13}$$

[1]Here we do not consider off-balance sheet risk exposures.

Denoting $NSFR_{min}$ as the minimum regulatory requirement and $NSFR_i$ as the actual ratio of bank i, it is required by the NSFR regulation that

$$NSFR_i = \frac{ASF_i}{RSF_i} = \frac{E_i + \beta D_i}{\epsilon * L_i} \geq NSFR_{min}. \tag{14}$$

Combining Equations 1 and 14, the maximum money supply of bank i under NSFR regulation can be obtained as follows,

$$D_{i,max}^{NSFR} = \frac{e_i + \epsilon NSFR_{min}}{\epsilon NSFR_{min} - \beta} \cdot R_i, \tag{15}$$

where $\beta < \epsilon NSFR_{min}$[2]. Then the ratio of deposits to reserves of bank i can be presented by

$$m_i^{NSFR} = \frac{e_i + \epsilon NSFR_{min}}{\epsilon NSFR_{min} - \beta}. \tag{16}$$

Correspondingly, the maximum amount of loans under NSFR regulation can be derived as well, expressed as

$$L_{i,max}^{NSFR} = \frac{(1-\beta)e_i + \beta}{\epsilon NSFR_{min} - \beta} \cdot R_i. \tag{17}$$

It is obvious from Equation 15 that ($D_{i,max}^{NSFR}$) is negatively related with $NSFR_{min}$, suggesting that a stricter requirement on net stable funding would lead to a decrease in money supply. As long as bank i is under the regulation of NSFR, its equity to reserve ratio e_i is positively related to its money supply.

The above two regulatory instruments focus on banks' liquidity risks, and each of them requires banks to hold a certain amount of reserves (or other liquidity assets). In other words, banks who hold a certain amount of reserves, could expand their balance sheets until they reach an upper limit which can be determined by their corresponding regulatory instruments, which can be shown in Fig.1(a) and (b).

2.2.3. The risk-based capital adequacy ratio (CAR)

The regulation on CAR requires banks to hold adequate capital to guard against solvency risks. Suppose that the actual risk-based capital adequacy ratio of bank i is denoted by CAR_i and the corresponding minimum value is denoted by CAR_{min} respectively. And the only risky asset is loans with an average risk weight of γ, then the risk-weighted assets RWA_i can be computed as

$$RWA_i = \gamma L_i. \tag{18}$$

[2]Note that the NSFR regulation puts no constraint on money creation when $\beta \geq \epsilon NSFR_{min}$, because the stability of deposits is higher than that of loans under this condition.

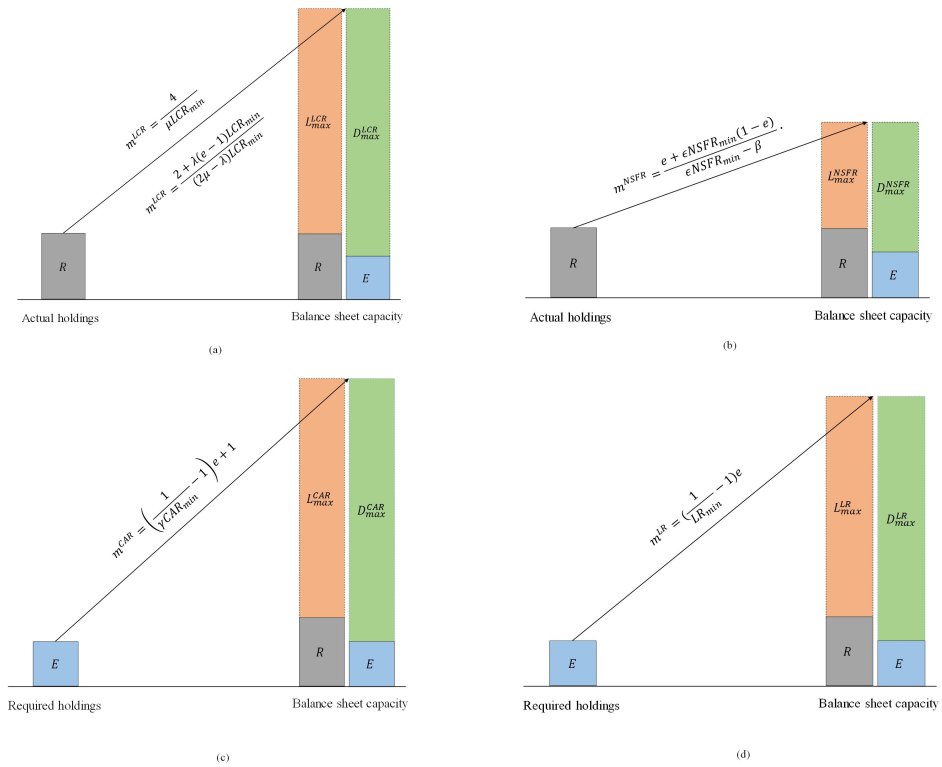


Figure 1: Schematic illustration of how regulatory requirements affect balance sheet capacity given actual holdings of reserves and equities: (a) LCR, (b) NSFR, (c) CAR, (d) LR respectively.

Therefore, bank i must comply with CAR requirement where the real CAR_i must be greater than or equal to CAR_{min}, which can be expressed as

$$CAR_i = \frac{E_i}{RWA_i} = \frac{E_i}{\gamma L_i} \geq CAR_{min}. \tag{19}$$

The maximum amount of loans of bank i under CAR regulation can be obtained straightforwardly

$$L_{i,max}^{CAR} = \frac{e_i}{\gamma CAR_{min}} \cdot R_i. \tag{20}$$

Combining Equations 1 and 20, the maximum money supply provided by bank i under CAR requirement can be derived at as follows

$$D_{i,max}^{CAR} = [(\frac{1}{\gamma CAR_{min}} - 1)e_i + 1] \cdot R_i. \tag{21}$$

And then the ratio of deposits to reserves of bank i can be computed as

$$m_i^{CAR} = [(\frac{1}{\gamma CAR_{min}} - 1)e_i + 1]. \tag{22}$$

From Equation 21, we can firstly draw the conclusion that $D_{i,max}^{CAR}$ is an increasing function of e_i. Moreover, a stricter CAR regulation (i.e. larger CAR_{min}) would lead to a lower level of money supply since it is mainly imposed on the base of equity.

2.2.4. The leverage ratio (LR)

With the similar purpose of CAR requirement, LR is a non-risk requirement that restricts the scale of assets. The actual leverage ratio of bank i is denoted by LR_i, which can be computed as

$$LR_i = \frac{E_i}{TA_i}, \tag{23}$$

where E_i is the amount of equity of bank i and TA_i is that of total assets. In this model, total assets can be calculated by the summation of loans and reserves, which is given by

$$TA_i = L_i + R_i. \tag{24}$$

According to the requirement of leverage regulation, the actual LR_i should be no less than the corresponding minimum level LR_{min}, that is

$$LR_i = \frac{E_i}{L_i + R_i} \geq LR_{min}. \tag{25}$$

In the same way, we can derive at the maximum amount of loans of bank i under LR regulation which takes the following form

$$L_{i,max}^{LR} = (\frac{e_i}{LR_{min}} - 1) \cdot R_i. \tag{26}$$

And the corresponding money supply under LR regulation can be given by

$$D_{i,max}^{LR} = (\frac{1}{LR_{min}} - 1)e_i \cdot R_i. \tag{27}$$

Then the ratio of deposits to reserves of bank i can be obtained

$$m_i^{LR} = (\frac{1}{LR_{min}} - 1)e_i. \tag{28}$$

From Equation 27, we can see that $D_{i,max}^{LR}$ is a decreasing function of LR_{min}. Moreover, LR regulation, similar to CAR, is also primarily implemented on equity, so a tighter LR requirement would also decrease the total money supply.

Furthermore, the above two regulatory instruments protect banks from solvency risks, and each of them requires banks to hold a certain amount of capital. That is to say, banks can only expand their balance sheets toward a limit determined both by their capital holdings and the corresponding capital regulatory ratios, demonstrated by Fig.1 (c) and (d).

2.3. The collective impacts of multiple regulations

In Section 2.2, we have obtained the expressions of money supply provided by one bank when it is solely bound by a single prudential regulation. However, in the real world, banks must be subject to multiple regulatory instruments at the same time. Next, we will examine the collective impacts of multiple regulations on money supply. When a bank is under the restrictions of more than one prudential regulations, its capability of money creation is confined to the most stringent constraint. By comparing the values of maximum loans each bank could extend, which corresponds to the effective binding regulation, we obtain the final expression of maximum outstanding loans for bank i, given by

$$L_{i,max} = \min\{L_{i,max}^{LCR}, L_{i,max}^{NSFR}, L_{i,max}^{CAR}, L_{i,max}^{LR}\}. \tag{29}$$

Following the same procedure, we can obtain the expressions of money supply provided by bank i when it is constrained by multiple regulations, expressed as

$$D_{i,max} = \min\{D_{i,max}^{LCR}, D_{i,max}^{NSFR}, D_{i,max}^{CAR}, D_{i,max}^{LR}\}. \tag{30}$$

Since there is no cash in the economy, the broad money can be computed as the summation of maximum deposits of all banks, presented by

$$M_s = \sum_i D_{i,max}. \tag{31}$$

3. The model with liquidity trading in the interbank market

In Section 2, we have demonstrated the determination of money supply provided by each bank and its corresponding binding regulation, shown both in Equations 29 and 30. According to these calculations, we may define the position of each bank i, that is, whether bank i is with liquidity surplus or with liquidity shortage. Specifically, when the bank is bound by either of the capital regulations (CAR and LR), it is in the position of liquidity excess. These banks who are with liquidity surplus position have the potential to supply liquidity in the interbank market. And we use subset $\{N_s\}$ to represent liquidity suppliers, if $i \in \{N_s\}$, then bank i is in the position of liquidity surplus possibly acting as a liquidity supplier in the interbank market, whose balance sheet could be presented by Table. 2. In the opposite, when the bank is bound by either of the liquidity regulations (LCR and NSFR), it is in the position of liquidity shortage, under which circumstance it could further extend its balance sheet if it is injected with additional liquidity. We then define a subset of liquidity demanders, denoted by $\{N_d\}$. If $j \in \{N_d\}$, then bank j is in the position of liquidity shortage, whose balance sheet is presented by Table. 3. Since the money creation of each bank in the whole system is bound either by liquidity regulations or capital regulations, as a consequence, each bank would either act as a liquidity supplier or as a demander, we must have the following relationship,

$$\{N_s\} \cup \{N_d\} = \{N\}. \tag{32}$$

Table 2: The balance sheet for bank i with liquidity surplus

Assets	Liabilities
Reserves ($\widetilde{R_i}$)	Deposits ($\widetilde{D_i}$)
Loans ($\widetilde{L_i}$)	Equity ($\widetilde{E_i}$)
Interbank loans ($\widetilde{IL_i}$)	

Table 3: The balance sheet for bank j with liquidity shortage

Assets	Liabilities
Reserves ($\widetilde{R_j}$)	Deposits ($\widetilde{D_j}$)
Loans ($\widetilde{L_j}$)	Equity ($\widetilde{E_j}$)
	Interbank loans ($\widetilde{IL_j}$)

3.1. Supply of liquidity

For bank i, who is in the position of liquidity surplus as defined above ($i \in \{N_s\}$), the amount of its liquidity supply is governed by the difference between its actual holdings of liquid assets and the required one. So the quantity of liquidity supply of bank i can be mathematically given by

$$\widetilde{LS_i} = \rho \cdot \min\{\widetilde{HQLA_i} - LCR_{min} \cdot \widetilde{NCOF}, \widetilde{ASF_i} - NSFR_{min} \cdot \widetilde{RSF_i}\}, \tag{33}$$

where ρ represents the confidence factor of banks in the interbank market. A higher ρ represents better economic conditions, thus banks would have higher confidence in the market. And therefore, the aggregate amount of liquidity supply LS can be obtained by summing up the individual liquidity supply, that is,

$$LS = \sum_i \widetilde{LS_i}, i \in \{N_s\}. \tag{34}$$

3.2. Demand for liquidity

For bank j, who is in the position of liquidity shortage as defined above ($j \in \{N_s\}$), the amount of its demand for liquidity depends on how much high quality liquid assets it needs to change its balance sheet structure thus it can fully meet the requirements from liquidity regulations. As can be inferred from Equations 10, 16, 22 and 28, the binding regulation each bank is subject to is determined by the equity to reserve ratio e_j, which represents bank's balance sheet structure. As a result, the transition conditions from liquidity binding regulations to capital binding regulations can be obtained by solving the equality of the values of each pair of expressions of money multipliers.

In specific, if bank j is previously bound by LCR regulation, then the transition conditions to switch to the structure which is bound by CAR regulation are respectively given by

$$\frac{4}{\mu LCR_{min}} = (\frac{1}{\gamma CAR_{min}} - 1)e_j + 1, \tag{35}$$

$$\frac{2 + \lambda(e_i - 1)LCR_{min}}{(2\mu - \lambda)LCR_{min}} = (\frac{1}{\gamma CAR_{min}} - 1)e_j + 1. \tag{36}$$

The solutions to Equations 35 and 36 are as follows,

$$e_1^\star = \frac{\gamma CAR_{min}(4 - \mu LCR_{min})}{\mu LCR_{min}(1 - \gamma CAR_{min})}, \tag{37}$$

$$e_2^\star = \frac{\gamma CAR_{min}(1 - \mu LCR_{min})}{LCR_{min}(\mu - 0.5\lambda - \mu\lambda CAR_{min})}. \tag{38}$$

Likewise, the transition conditions for bank j to switch to the structure which would be bound by LR regulation can be presented following the same procedure, that is,

$$\frac{4}{\mu LCR_{min}} = (\frac{1}{LR_{min}} - 1)e_j, \tag{39}$$

$$\frac{2 + \lambda(e_i - 1)LCR_{min}}{(2\mu - \lambda)LCR_{min}} = (\frac{1}{LR_{min}} - 1)e_j. \tag{40}$$

The solutions to Equations 39 and 40 are as follows,

$$e_3^\star = \frac{4LR_{min}}{\mu LCR_{min}(1 - LR_{min})}, \tag{41}$$

$$e_4^\star = \frac{LR_{min}(1 - 0.5\lambda LCR_{min})}{LCR_{min}[(1 - LR_{min})\mu - 0.5\lambda]}. \tag{42}$$

Thus for bank j, its demand for liquidity LD_j can be expressed as

$$\widetilde{LD}_j = \frac{\widetilde{E}_i}{\max\{e_1^\star, e_2^\star, e_3^\star, e_4^\star\}} - \widetilde{R}_j. \tag{43}$$

Furthermore, if bank j is previously bound by NSFR regulation, then the transition condition to switch to the structure which is bound by CAR regulation is given by

$$\frac{e_j + \epsilon NSFR_{min}(1 - e_j)}{\epsilon NSFR_{min} - \beta} = (\frac{1}{\gamma CAR_{min}} - 1)e_j + 1. \tag{44}$$

The solution to Equation 44 is shown below

$$e_5^\star = \frac{\frac{-\beta}{\epsilon NSFR_{min} - \beta}}{\frac{1 - \epsilon NSFR_{min}}{\epsilon NSFR_{min}} - \frac{1}{\gamma CAR_{min}} + 1}. \tag{45}$$

Similarly, the transition condition for bank j to switch to the structure which is bound by LR regulation is given by

$$\frac{e_j + \epsilon NSFR_{min}(1 - e_j)}{\epsilon NSFR_{min} - \beta} = (\frac{1}{LR_{min}} - 1)e_j. \tag{46}$$

The solution to Equation 46 can be given by

$$e_6^\star = \frac{\frac{-\epsilon NSFR_{min}}{\epsilon NSFR_{min} - \beta}}{\frac{1 - \epsilon NSFR_{min}}{\epsilon NSFR_{min}} - \frac{1}{LR_{min}} + 1}. \tag{47}$$

Thus for bank j, its demand for liquidity LD_j can be calculated as

$$\widetilde{LD}_j = \frac{\widetilde{E}_j}{\max\{e_5^\star, e_6^\star\}} - \widetilde{R}_j. \tag{48}$$

3.3. Trading mechanism in the interbank market

We employ the trading mechanism proposed by Popoyan et al., which is similar to real markets [61, 62], and we assume that trading in the interbank market is managed by a Central Clearing Counterparty (CCP), that matches demand and supply on a pecking-order basis. First, banks demanding liquidity and those supplying liquidity are sorted in a descending order. In this way, the first bank on the demand side is the one with the largest liquidity demand. Likewise, the first bank on the supply side is the one with the largest supply. Next, the first liquidity demander is matched to all liquidity suppliers starting from the bank with the largest liquidity supply, and then moving to the second if demand is not fully matched, etc. The liquidity provided to a bank is subtracted from the total liquidity provided by a supplier. Finally, once the liquidity demand of a bank is fully matched, the matching algorithm moves to the second bank in the demand's queue and the procedure is repeated until either liquidity demand

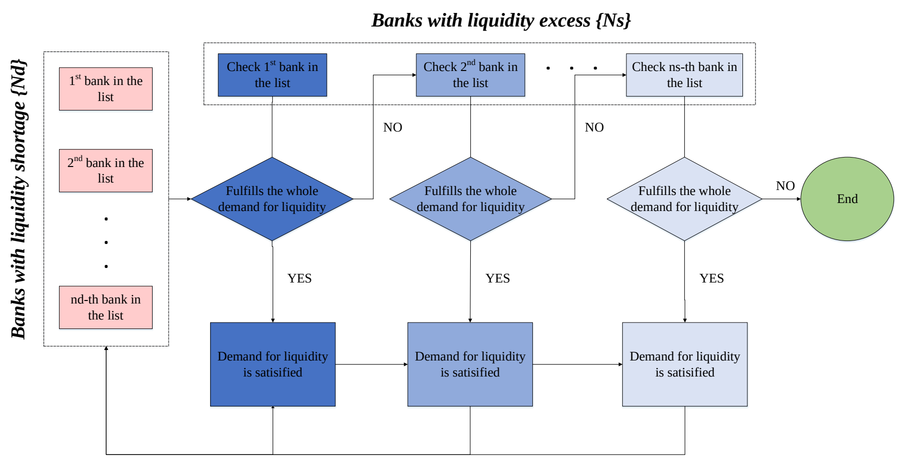


Figure 2: Representation of the matching algorithm in the interbank market.

is fully satisfied or liquidity supply is used up. The flow diagram in Fig. 2 provides an illusreation of the procedure that we have just described.

After the procedure of supply and demand matching, bank j with liquidity shortage would be endowed with an actual amount of interbank borrowing from bank i, denoted by $\widetilde{BL}_{ij}$. And then the aggregate amount of interbank borrowing would be obtained by summing up the interbank borrowing from all bank j's creditors, given by

$$\widetilde{BL}_j = \sum_i \widetilde{BL}_{ij}, j \in \{N_s\}, i \in \{N_s\}. \tag{49}$$

As a result, the corresponding changes to liquidity demander bank j's balance sheet should be listed as follows,

$$\widetilde{R}_j = R_j + \widetilde{BL}_j, \tag{50}$$

$$\widetilde{IL}_j = IL_j + \widetilde{BL}_j. \tag{51}$$

In addition, the aggregate amount of interbank lending of bank i with liquidity excess could also be obtained by summing up all the lending to bank i's debtors, which is expressed as

$$\widetilde{BL}_i = \sum_j \widetilde{BL}_{ij}, i \in \{N_s\}, j \in \{N_s\}. \tag{52}$$

As a result, the corresponding changes to liquidity supplier bank i's balance sheet should be listed as follows,

$$\widetilde{R_i} = R_i - \widetilde{BL_i}, \tag{53}$$

$$\widetilde{IL_i} = IL_i + \widetilde{BL_i}. \tag{54}$$

In the end, we obtain the expression of money supply provided by each bank, $\widetilde{D_{i,max}}$ by conducting the same the calculations presented in Section 3. Then we could derive at the broad money in the model with the interbank market by summing up all the deposits of individual banks, given by

$$\widetilde{M_s} = \sum_i \widetilde{D_{i,max}}. \tag{55}$$

4. Simulation results

In this section, we perform several numerical calculations so as to present the impact of interbank market on money supply. Our first concern is how much of increase in money supply would be caused by the interbank liquidity trading. While our second concern is how the collective impacts of multiple regulations would vary with the interbank liquidity trading. So we calculate the money supply both in the benchmark model as well as in the model with interbank market, then we compare these two quantities of money supply to show the impact of the interbank market. Last but not least, the aggregate liquidity position (specifically, to consider the banking system as a whole, whether it is with liquidity surplus or liquidity shortage) would determine the variation of money supply caused by interbank market. In order to clearly demonstrate how the model runs, we present a flowchart in Fig. 3.

In the following analyses, the regulation-related parameters, LCR_{min}, $NSFR_{min}$, CAR_{min} and LR_{min}, basically represent the regulatory environment, which are mainly prescribed in the Basel III accord, so we set $LCR_{min} = 100\%$, $NSFR_{min} = 100\%$, $CAR_{min} = 7\%$ and $LR_{min} = 3\%$. The settings of other variables and environmental parameters are initially given as $N = 1000$, $E = \sum E_i = 10^5$, $\mu = 0.08$, $\lambda = 0.005$, $\gamma = 0.1$, $\beta = 0.2$ and $\epsilon = 0.3$. At first, we fix the confidence factor and the value of aggregate amount of equity E, we vary the amount of aggregate reserves R thus controlling the aggregate equity to reserve ratio e. As shown in Fig. 4, the process of liquidity injection is in equivalence with that of e lowering down, if we fix the amount of equity. Since the aggregate equity to reserve ratio portrays the balance sheet structure of the whole banking system, which would play a central role in determining the variation of money supply compared with that in a benchmark. Specifically, the blue curve in Fig. 4 represent the dependency of money supply variation ΔM and aggregate equity to reserve ratio e of the banking system when the confidence factor is 1, and the green along with the pink curves represent those when the confidence factor is 0.7 and 0.4 respectively. Firstly, we can conclude from blue curve in Fig. 4 that

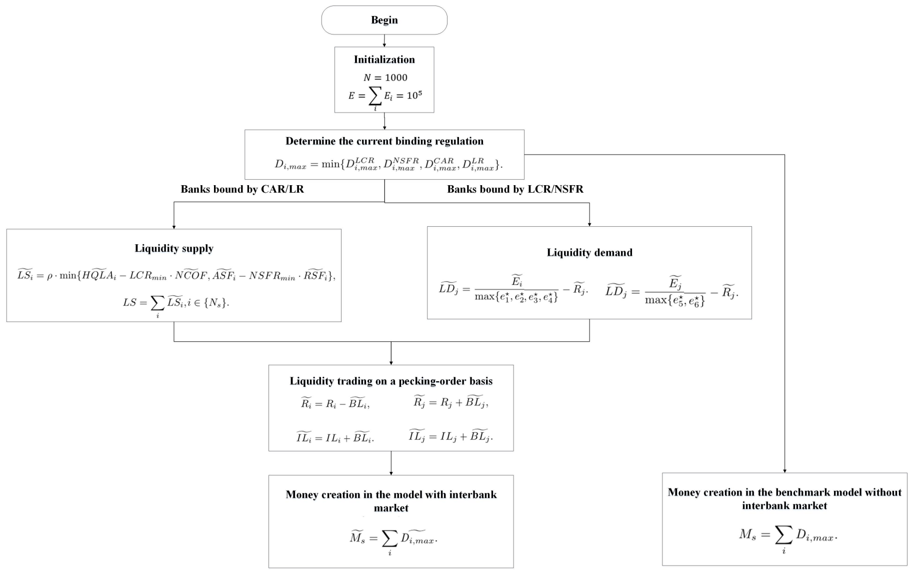


Figure 3: A flowchart of the economic procedure.

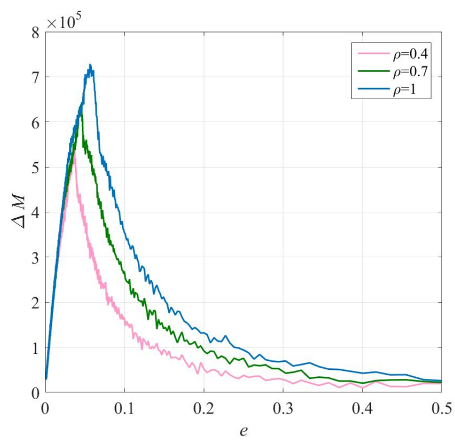


Figure 4: Dependency of variation of money supply on the aggregate equity to reserve ratio with fixed settings of parameters: $\mu = 0.08$, $\lambda = 0.005$, $\gamma = 0.1$, $\beta = 0.2$ and $\epsilon = 0.3$.

as e decrease from 0.1 to 0.06, implying that the amount of reserves is increasing, the effect of money supply increase is monotonically growing. However, when e is approximately 0.06, this effect reaches its maximum, and begins to decrease while still positive. This suggests that the central bank cannot always promote money supply by simply injecting reserves into the interbank market, the effect depends largely on the position the whole banking system is staying. Moreover, from the three curves in Fig. 4, we may find that the $e^\star$ where the maximum value of ΔM appears is different for different values of confidence factor. The banking systems with lower confidence will need more liquidity injection to convert its position from liquidity shortage to excess.

Moreover, what we are concerned about are the relationships between money supply and confidence factor in a banking system given the aggregate equity to reserve ratio. As shown in Fig. 5 (a), (b), (c) and (d), the money supply of the model with interbank market is greater than in that of the benchmark, however, the difference may vary with different levels of confidence. Furthermore, in order to promote the aggregate money supply, the efficiency of enhancing bank's confidence varies as well based on the balance sheet structure of the whole banking system. Take Fig. 5 (a) as an example, where the aggregate

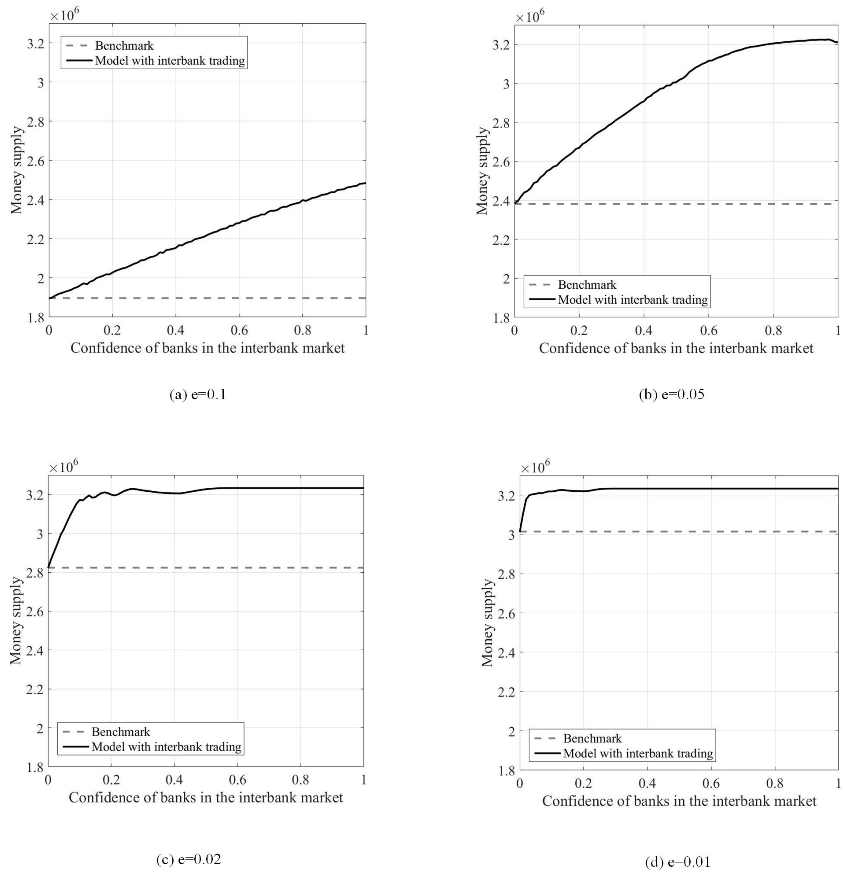
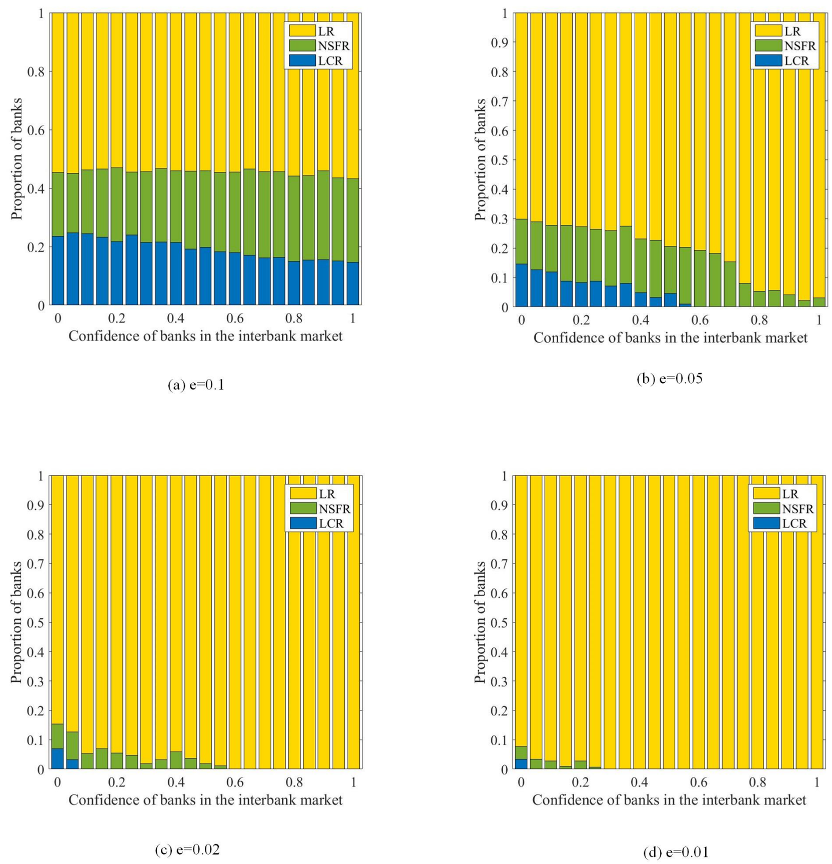


Figure 5: The dependency of Money supply on confidence factor with fixed settings of parameters: $\mu = 0.08$, $\lambda = 0.005$, $\gamma = 0.1$, $\beta = 0.2$ and $\epsilon = 0.3$ while (a) $e = 0.1$, (b) $e = 0.05$, (c) $e = 0.02$, (d) $e = 0.01$.



(a) e=0.1

(b) e=0.05

(c) e=0.02

(d) e=0.01

Figure 6: The dependency of proportion of banks on confidence factor whose binding regulation corresponds respectively to liquidity coverage regulation (blue bar), net stable funding regulation (green bar), leverage regulation (yellow bar) with fixed settings of parameters: $\mu = 0.08$, $\lambda = 0.005$, $\gamma = 0.1$, $\beta = 0.2$ and $\epsilon = 0.3$ while (a) $e = 0.1$, (b) $e = 0.05$, (c) $e = 0.02$, (d) $e = 0.01$.

equity to reserve ratio is at a relatively high level, we can obviously find that the corresponding effect grows up along with the stronger confidence in the market. When e is 0.05 as demonstrated by Fig. 5 (b), the increase of confidence factor is effective at the beginning from 0 to 0.9 approximately, while it later remains unchanged, which suggests that the promotion of banks' confidence no longer takes effect. Things become totally different when e lowers down to a relatively low level, for instance, $e = 0.02$ or 0.01 as shown in Fig. 5 (c) and (d), the effect of increase in money supply starts to be flat against the increase of the confidence factor at the very beginning. In these simulations, the value of aggregate equity to reserve ratio would represent the amount of total reserves since we fix the quantity of equity. When e is high, representing that the amount of reserves is not sufficient for the system, a higher level of banks' confidence may promote the trading between them, thus leading to a larger overall money supply. Nevertheless, when e is low, representing that the reserves are abundant, the promotion of trading in the interbank market could be effective while has a limit.

The results in Fig. 5 can be better understood by Fig. 6, where the dependency of proportions of banks under each binding regulation on the confidence factor are displayed. As shown in Fig. 6 (a) and (b), both the yellow and blue bars represent the proportion of banks which are bound by liquidity regulations, that is to say, they are potentially the liquidity demanders in the interbank market, while green bars represent that of banks bound by capital regulations, that is to say, they are potentially liquidity suppliers in the market. We may definitely find that the proportion of banks bound by liquidity regulations is decreasing along with banks' stronger confidence in the market only when the aggregate equity to reserve ratio is at a relatively high level. However, as shown in Fig. 6 (c) and (d), when the confidence factor is equal to 0.5 and 0.25 respectively, the increase of confidence would bring about no changes to the binding regulation for each bank because all of them are bound by capital regulations, suggesting that the interbank liquidity demands are fully satisfied, reaching the market saturation.

5. Concluding remarks

Multiple regulations would have constraining effect on the overall money supply, this paper demonstrates the adverse impact of interbank liquidity trading on the overall money supply. We present an agent-based model of commercial banks where each is endowed with diverse amounts of reserves and equities thus they are bound by different binding regulations. In the interbank market, those banks act as either liquidity suppliers or liquidity demanders, depending on which of the regulatory instruments takes effect. By numerical calculations, we find that both the confidence factor and the aggregate equity to reserve ratio play significant roles in determining the variation of money supply. Promoting banks' confidence in the interbank market can be of help in redistributing liquidity among banks, thus may help increasing money supply. While this effect can be influenced by the liquidity position of the whole banking system. Furthermore, the injection of liquidity would only be effective in promoting aggregate money supply when the system is in shortage for liquidity. However, when the system is already with liquidity surplus, liquidity injection would have no impact on money supply, otherwise have some adverse effect on money multiplier.

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