Economics
The Open-Access, Open-Assessment E-Journal

Discussion Paper
No. 2017-2 | January 23, 2017 | http://www.economics-ejournal.org/economics/discussionpapers/2017-2

The impact of the Basel III liquidity coverage ratio on macroeconomic stability: an agent-based approach

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Abstract
Commercial banks across the world have been implementing the Basel III accord, which is the most important international response to the 2007–2008 financial crisis. Particularly, the liquidity coverage ratio (LCR) introduced by the Basel III accord is the first global standard for banking liquidity management. Does this requirement work? And what macroeconomic effects does it produce? In order to address such crucial issues, the author develops a stock-flow consistent (SFC)/agent-based computational economic (ACE) model. As he knows, there is a real danger that the requirement restricts the availability of bank credit and hence reducing economic activity. However, in comparison to the prior works, the author finds that the externality is presented as a positive self-reinforcing feedback process, which causes the macroeconomic conditions to spiral downwards. This dynamic feedback process that hardly can be revealed by the current macroeconomic models based on equilibrium analyses. The results also shed some light on the fact that credit creation substantially affects economic activity and macroeconomic stability, as the fundamental reason leading to the results. Therefore, the bank as the driver of credit creation is crucial in an economy, and meanwhile bank regulations have great potential impacts on entire economy rather than only in the bank sector itself.

JEL E27 E44 E51 E32 G01 G28
Keywords Credit creation; liquidity coverage ratio; bank regulation; economic stability; agent-based macroeconomics; stock-flow consistency; business cycle; crisis

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Citation Boyao Li (2017). The impact of the Basel III liquidity coverage ratio on macroeconomic stability: an agent-based approach. Economics Discussion Papers, No 2017-2, Kiel Institute for the World Economy. http://www.economics-ejournal.org/economics/discussionpapers/2017-2

Received January 10, 2017 **Accepted as Economics Discussion Paper** January 19, 2017 **Published** January 23, 2017

1 Introduction

The 2007-2008 financial crisis drags the global economy into a deep and long-lasting recession. Despite those multiple possible causes of the crisis explored by a series of prominent works, e.g., financial deregulation (Crotty, 2009), loose monetary policy (Taylor, 2009), global imbalances (Obstfeld and Rogoff, 2009), misperception of risk (Baily et al., 2011); however, there should be little debate with the main origin of this disaster: the excessive credit created by the banking systems (Acharya and Richardson, 2009; Farhi and Tirole, 2012; Kashyap et al., 2008; Liikanen, 2012; Schularick and Taylor, 2012; Stiglitz, 2009; Vickers, 2011). Essentially, this widely accepted opinion is rooted in the basic understanding on the role of commercial banks that the credit granted by them is accepted and circulated as money—a feature unique to bank credit (McLeay et al., 2014a,b; Werner, 2014a,b). Accordingly, it is extremely necessary and urgent to revise and enhance the regulatory rules for banks, which did not effectively constraint the excessive bank lending and also not follow the track of financial development in recent decades.

In response to these deficiencies of bank regulations revealed by this crisis, the Basel Committee on Banking Supervision (BCBS) published the Basel III document: A global regulatory framework for more resilient banks and banking systems (BCBS, 2011), in order to strengthen the regulation, supervision, and risk management of the bank sector. It is noteworthy that this document introduces for the first time a global framework for liquidity management as the response to the most important lesson learned from the crisis that the capital requirement alone is not sufficient to maintain a sound banking system (Allen and Carletti, 2008; Borio, 2010, 2008; Brunnermeier, 2008; Tirole, 2011). Basel III introduces the Liquidity Coverage Ratio (LCR) (BCBS, 2013) and Net Stable Funding Ratio (NSFR) (BCBS, 2014a), two separate but complementary minimum standards for funding liquidity. The LCR is a minimum standard for funding liquidity in short-term for commercial banks, and the Net Stable Funding Ratio (NSFR) aims at promoting medium and longer-term funding of the assets and activities of banks.

Considering the widespread and profound influences of the Basel accords, this last version is gradually approved and adopted around the world (BCBS, 2014b,c). However, up to present, people have not yet obtained a consistent and definite answer on the effects of these new regulations, that is, how these updated regulations affect banking conditions and economic activities remain open questions. Furthermore, these plausible requirements and regulations may plant the seeds of new hazards. It is impossible to examine them until the financial crisis recurs. Therefore, it is urgent to provide a theoretical analysis on the question in advance. Following the evolution of the perspective on bank regulations, the objective of bank regulations has switched from focusing on the stability of individual institutions to the macroeconomic stability. In line with this fact, a growing number of central banks and monetary authorities regard the macroeconomic performances of a bank regulation as the final criterion to its effectiveness (Clement, 2010).

The priority here is to build a suitable and powerful model to measure the valid outcomes of the bank-regulatory reforms. Therefore, it is primary to identify what characteristics the model should have. Basically, there are two ruling paradigm of today's macroeconomics based on two fundamental pillars. One is a behavioral underpinning of individual economic units, which can provide a sound micro foundation. The other is a proper system view that focuses on macroeconomic performance resulting from the behavioral underpinning (Bezemer, 2012). The system view includes at least two aspects. First, the model should allow for those cross-sectional and intertemporal coordination failures that lie at the heart of business fluctuations and financial instability, which makes it necessary to introduce heterogeneity and inconsistent expectation at the individual agent level (Arnold et al., 2012; Borio, 2011). Second, it should present the dynamic process out of equilibrium so that the disequilibrium process, such as leveraging and deleveraging, the basic financial processes can be properly modeled (Arthur, 2006; Bezemer, 2012; Godley and Shaikh, 2002; Kirman, 2010). Going one step further, a model integrates the bank sector with the function of creating loans as well as aggregate demand, as is indispensable to address this issue (Arnold et al., 2012; Borio, 2011; Borio and Disyatat, 2011).

On the heels of this crisis, a multiplying number of efforts have been devoted to this issue. As might be expected, the main works are those of integrating banking systems into the dynamic stochastic general equilibrium models (DSGEs) , the workhorse model for modern macroeconomics, and still considered as the valid model to understand the interaction between the financial system and the real economy. Therefore, one or some particular factors of financial system embedded in DSGEs sharply emerged after the crisis (e.g., Andrés and Arce, 2012; Angeloni et al., 2015; Brunnermeier and Sannikov, 2014; Christiano et al., 2010; Cúrdia and Woodford, 2010; Dib, 2010a; Gerali et al., 2010; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010; Goodfriend and McCallum, 2007; Meh and Moran, 2010). These efforts can undoubtedly be adopted to understand the impacts of Basel III regulations; nevertheless, the major characteristics of the DSGEs are a radical departure from the way of addressing this issue. More concretely, the representative agent as well as perfect foresight (Ackerman, 2002; Akerlof, 2002; Fair, 2012; Gaffeo et al., 2008) are default assumption of the DSGEs. What's worse, there is a fundamental flaw in the system view of the DSGEs that they assume equivalence between the micro and the macro behavior. Hence, it is hard to take into account the interaction and coordination properly among economic agents in the DSGEs (Arthur, 2006; Axtell, 2007; Epstein, 1999). In addition, as criticized by many scholars (Arthur, 2006; Caballero, 2010; Colander et al., 2009, 2008;

Gatti et al., 2010; Kirman, 2010), they share with traditional general equilibrium models (GEs) the same problem and weakness that none of them can show the full dynamics outside equilibrium. Accordingly, they only analyse the deviations from steady states, which are independent of financial regulation and do not model financial booms and busts (Bean, 2010; Buiter, 2009; Gatti et al., 2010; Tovar, 2009). Moreover, the monetary side of the model is fully determined in the real sphere resulting in absence of an appropriate way of modeling financial markets (Bezemer, 2012; Tovar, 2009). Therefore, these models are hardly suited for analysing the macroeconomic impacts of the monetary policy and bank regulation, and their conclusions may bring serious consequences in practice (Colander, 2006).

To respond to these raised criticisms, one of the most successful research project is that known in the literature as the agent-based computational economic (ACE) model (Tesfatsion and Judd, 2006). The ACE model is comprised of multiple interacting agents with behavioral rules. The macro outcomes thus emerge from micro behaviors and interactions endogenously. Hence, bounded rationality, heterogeneous agents, and a bottom-up perspective are the outstanding features of these models, as seems well suited for the analysis of endogenous economic processes and even crises (Axtell, 2007; Fagiolo and Roventini, 2016, 2012; Gatti et al., 2011, 2010; LeBaron and Tesfatsion, 2008). What's more, this method highlights the dynamic evolution of the economy as a complex adaptive system and discards the general equilibrium perspective of the orthodox macroeconomic model (Arthur, 2006; Colander et al., 2008; Kirman, 2010).

Nevertheless, The ACE model constitutes a method rather than a theory; it provides a systematic way to incorporate whatever elements a researcher believes are useful for the exploratory study of a particular economic phenomenon (Bezemer, 2012, 2011a; Tesfatsion, 2007). It is not the answer to which theory is capable of validly modeling a macroeconomic system with financial factors. To find the answer, Bezemer (2011b) surveys the research methods adopted by the works that successfully anticipated the 2007-2008 financial crisis and identifies the common features in these works. As Bezemer (2011b) indicates, those models emphasize money, the flow of funds, and accounting relations in the economy. The flow-of-fund models and their wider class stock-flow consistent (SFC) models (also including real variables) (Godley, 1999; Godley and Lavoie, 2007) meet all these requirements (Bezemer, 2012, 2011b, 2010). Therefore, it should be the most promising approach that the ACE model as a powerful method marrying to the SFC model as a proven theory, as invocated by Bezemer (2012, 2010); Caverzasi and Godin (2013); Kinsella et al. (2011); Riccetti et al. (2015); Seppecher and Salle (2015); Teglio et al. (2010a). In particular, this approach explicitly models every single agent's balance sheet at every point in time and considers dynamics of the financial flows between the agents; because of these features, it is called the "balance sheet approach" (Bezemer, 2012, 2010; Cincotti et al., 2012b; Teglio et al., 2010a).

The balance sheet approach has an explicitly modeling of the bank sector and emphasizes the role of financial factors in such a way that introducing a credit market between commercial banks and firms is characterized by decentralized exchange, market disequilibrium, and risk propagation. In recent years, especially the aftermath of this financial crisis, there has been a great deal of attention given to the development of this type of model (Cincotti et al., 2012b, 2010; Kinsella et al., 2011; Raberto et al., 2012, 2008; Riccetti et al., 2013, 2015; Teglio et al., 2010b). In addition, these models can be enriched by adding the interbank market, which creates endogenous counterparty risks that is driven and amplified by banks' correlated behaviors and defaults (Krug et al., 2015; Lengnick et al., 2013).

As the outstanding feature of these models, they are extremely useful to deal with computational experiments on regulatory issues and test the impacts of different policy interventions (Fagiolo and Roventini, 2016, 2012). Some of these works using the balance sheet approach provide the effective examinations on the regulations of the Basel accords. Taking advantage of the balance sheet approach models, these papers can provide endogenous out-of-equilibrium dynamics, which manifest the endogenous financial risks shaped by the exogenous policies so as to perform the policy tests. The majority of these works highlight the time series of the macroeconomic variables and financial factors. Teglio et al. (2012) show that a higher capital adequacy ratio offers more stability in long-run. Furthermore, the results of Cincotti et al. (2012a) support the effectiveness of the countercyclical capital buffer. Both these two works use the Eurace model. Riccetti et al. (2013) investigate the macroeconomic effects of capital requirements along with the credit risk concentrations, which is one of the most direct causes of the waves of bank failures witnessed during the recent financial crisis (Blundell-Wignall and Atkinson, 2010). In the other aspect, Krug et al. (2015) test the stability of the bank sector complying with different combinations of the Basel III regulations, and suggest some optimal ones

In our article, we will focus on dynamic evolutions of the important and meaningful macroeconomic indicators in the artificial economy in order to present the effects resulting from the banks complying with the LCR. Our core aim is to distinguish main macroeconomic outcomes between two scenarios: one is the banks complying with the Basel III LCR, the other is the banks only hoarding constant liquidity buffers.

After the Basel III accord published, it has been criticized that the LCR is nothing but a microprudential regulation rather than being macroprudential (Shin, 2011; van den End and Kruidhof, 2013). However, in our research, an unexpected adverse side effects caused by compliance with the LCR may destroy the macroeconomic stability. The process can be described as a positive feedback process: under the stressful situations, the bank struggles to "self-defense," i.e., the bank tends to hold a higher liquidity buffer to comply with the LCR, leading to cutting back on lending; but this type of reaction exacerbates the already stressful macroeconomic conditions, which causes the bank to resort to further "self-defense." The essential of the feedback process can be interpreted as an interaction between the real sector and the bank sector. In light of this, our analysis clearly indicates that the LCR as a prescription for the health of the banking system potentially turns out to be a poison to the whole economy under some stressful conditions. Our results also point out that the role of the bank at macroeconomic level is not a financial intermediary, but instead a core sector to generate macroeconomic effects.

2 The impacts of the new Basel III rules: a selective review of the literature

Basel III as the most recent version of the Basel international standards for bank regulation is designed to promote a more resilient bank sector. This reform regarding bank prudential regulations published by the BCBS aims at strengthening the resilience of the banking system by improving the bank sector's ability to absorb shocks arising from financial and economic stress. In order to reach these ultimate objectives, beyond having strengthened the well-known Capital Adequacy Requirement (CAR), Basel III introduces new liquidity requirements and macroprudential regulations. As we mentioned in Introduction, there are two new liquidity requirements of Basel III: the LCR requires a bank to hold sufficient unencumbered high-quality liquid assets (HQLA) to cover its total net cash outflows over 30 days, by contrast, the NSFR is to ensure a bank's available stable funding exceeding its required stable funding over a one year horizon. Besides, Basel III introduces new macroprudential regulations containing the capital countercyclical capital buffer (CCyB), i.e., a requirement for a banks to build up a buffer in good times that can be released in bad ones; and the capital surcharges for systemically important banks.

Introducing macroprudential regulations in Basel III is the response to the main criticism against the existing microprudential regulations, whose aim is focusing on safety and soundness of individual banks. In contrast, the ultimate goal of macroprudential regulations is to avoid or contain the costs they generate for the real economy (Borio, 2011, 2003; Brunnermeier et al., 2009; Crockett, 2000), that is, the macroprudential regulations are designed to foster and improve macroeconomic stability.

Before further discussing Basel III, we would like to clarify the criteria and requirements to achieve the macroeconomic stability. In recent years, the studies on financial and macroeconomic stability provide various conclusions on this issue belonging to different levels.

First, and earliest, "the whole financial system is sound if and only if each institution is sound," as is the core concept of traditional microprudential rules.

Second, there is a growing awareness of the need to maintain the resilience and robustness of the financial system as whole, which is mainly dependent on the network topology (Acemoglu et al., 2015; Allen and Babus, 2007; Allen and Gale, 2000; Battiston et al., 2016; Haldane, 2013). Moreover, the regulations should minimize the adverse spillover effects, such as cutting back on lending, fire sales, triggered by bank regulations affecting macroeconomic stability or dampening economic activity. In this strand, the top-down assessments of the macroeconomic/social benefits or costs of Basel III regulations, adopted by the BCBS (BCBS, 2010b,c) and some academic papers (Admati et al., 2013; Admati and Hellwig, 2014; Angelini et al., 2015; Angeloni and Faia, 2013; Cecchetti, 2014; Cincotti et al., 2012a; Dib, 2010b; Krug et al., 2015; Martinez-Miera and Suarez, 2012; Miles et al., 2013; Riccetti et al., 2013), take a stride to macroprudential direction. In order to strengthen the macroprudential orientation of regulatory and supervisory frameworks with respect to this strand, Basel III introduces the countercyclical capital buffer (CCyB) (BCBS, 2010a), despite the fact that it is very new and undergoing a variety of criticisms (Drehmann and Tsatsaronis, 2014) such as the objective of the buffer, conditioning variables (Drehmann et al., 2010; Drehmann and Juselius, 2014; Repullo and Saurina Salas, 2011), practical measurement problems (Drehmann et al., 2011; Edge and Meisenzahl, 2011), etc.

Third, the design of a bank regulation should consider the probable outcomes of the feedback between the financial system and the real economy, which still lacks research to date. Indeed, this flaw in design of the regulation has been pointed out. Specifically, the designs do not allow for the possibility of positive feedback effects between the financial system and the real economy in the build-up of the crisis, and those approaches were essentially static and treated the corresponding shocks as entirely exogenous (Borio, 2011).

As well known, the Basel III framework has shifted to macroprudential direction; nevertheless, it does not go far enough (Blundell-Wignall and Atkinson, 2010; Goodhart and Perotti, 2013; Kupiec, 2013; Shin, 2011), even the journey has probably just begun. It is recognized that going a step further calls for rethinking and fixing the fundamental flaw in the principle lying behind the prudential regulation of banks, e.g., the Basel III accord. As mentioned above, the effect of bank regulation can spill over into the real economy owing to the special externality of the bank sector—creating credit, or money. However, because the canonical macroeconomic models are almost incapable of modeling the feedback process between the financial system and the real economy, all of them only identify or assess some static spillover effects created by bank regulations. In fact, the static version can be seen as just the first round effect of the dynamic one. It is natural to ask how the dynamic spillover effects generated by the positive self-reinforcing feedback affect economy? To the best of our knowledge, we do not yet find a macroeconomic model to present this process and the corresponding outcomes.

Regarding this paper, we focus on one single regulation—the Liquidity Coverage Ratio (LCR) as an example to present the results. There are basically two reasons why the LCR deserves to be analysed according to our aims. On the one hand, our results challenge the current opinion of policymakers and supervisors on the liquidity management: “more is good," as was the view on capital in Basel I over two decades ago (Arnold et al., 2012). On the other hand, the LCR is a typical representative of Basel III regulations, to some extent, the results can be generalized to some other regulations of Basel III.

Finally, we expect that our results can offer some valuable clues to modify the current liquidity requirement of Basel III. So far, to mitigate the recognized negative effects, existing works propose some new approaches such as a contingent (Goodhart, 2013) or flexible liquidity requirement (van den End and Kruidhof, 2013) as a substitute for the LCR, or introducing Pigovian taxes (Perottia and Suarezb, 2011). They are in line with the conceptual framework of promising macroprudential regulations in order to foster macroeconomic stability. However, all of the proposals do not yet consider the feedback between the bank sector and real economy. On the other hand, all these modifications increase the complexity of the LCR to some extent. In fact, the complexity of Basel III rules has dramatically increased than the prior Basel accords, which probably causes serious questions on the robustness and the effectiveness of the Basel III framework, and generates greater uncertainties (Doris and Roger, 2014; Haldane and Madouros, 2012; Kupiec, 2013).

According to our conclusion, whichever modification that one adopts to address this issue should take account of this banks' dynamic externality as the potential positive feedback process rather than the static one; otherwise, the undesired side effects embodied in the adverse feedback loop, as our results presented, largely outweigh the benefits of the modification.

3 The model

3.1 A brief summary of the LCR

Before presenting our model, we briefly review the LCR of Basel III in this section. This summary abstracts from Basel III document: The liquidity coverage ratio and liquidity risk monitoring tools (BCBS, 2013). The LCR is calculated by the stock of the unencumbered high-quality liquid assets (HQLA) the bank holds divided by its total projected net cash outflows over a 30-day horizon under a stress scenario specified by supervisors.

$$\text{LCR} = \frac{\text{Stock of unencumbered high-quality liquid assets}}{\text{Total net cash outflows over the next 30 calendar days}}. \tag{1}$$

The minimum ratio will gradually approach to one from beginning of 1 January 2015 to 1 January 2019 planned in the document. That is, the bank should hold a liquidity buffer made up of HQLA to excess the required ratio. The HQLA are grouped into two classes. Cash, central bank reserves, and certain marketable securities backed by sovereigns and central banks, etc. belong to Level 1 class assets of HQLA, which can comprise an unlimited share of the buffer and are not subject to any haircut. In contrast, Level 2 assets, which are subject to some haircuts and quantitative caps, generally include certain government securities, corporate debt securities, covered bonds, etc.

The denominator, the total net cash outflows, is defined as the total expected cash outflows minus the total expected cash inflows in the specified stress scenario for the subsequent 30 calendar days. The total expected cash outflows are calculated by multiplying the outstanding balances of various categories or types of liabilities and off-balance sheet commitments by the rates at which they are expected to run off or be drawn down. The total expected cash inflows are calculated by multiplying the outstanding balances of various categories of contractual receivables by the rates at which they are expected to flow in under the scenario, up to an aggregate cap of 75% of the total expected cash outflows.

3.2 Overview

Our aim is to build a four-sector economic model using the balance sheet method. We have four different types of agents in our artificial economic model: households (HHs), firms (FIs), banks (BAs), and the central bank (CB). We set the number of the three types of agents: $HHs \gg FIs > BAs$. The central bank in our model plays a passive role as a governor who supervises the commercial banks to comply with the Basel III LCR and the reserve requirement. Meanwhile, we assume there are no central bank liquidity facilities. In addition, time comes in discrete steps in our model.

We build our model according to the balance sheet approach, which explicitly describes the states of every agent through the balance sheets. Besides, the changes of items occurring on the corresponding balance sheets, and the flows of funds naturally model the interactions between them (Bezemer, 2012, 2010; Cincotti et al., 2012b; Lengnick et al., 2013; Teglio et al., 2010a). Table 1 exemplifies the balance sheets of the three types of active agents. These are most elementary cells of our model.

Table 1: The balance sheet

(a) Household

Assets	Liabilities
Cash	
Deposits	
	Equity

(b) Firm

Assets	Liabilities
Fixed property	
Cash	Loans
	Equity

(c) Bank

Assets	Liabilities
Loans	Deposits
Interbank loans	
Liquidity buffer	
Required reserves	
Loanable funds	Interbank liabilities
	Equity

1. The household possesses two types of assets, cash and deposits.

2. There are also two items on the asset side of the firm's balance sheet. Fixed property includes machinery, plants, and implements, etc. We endow each firm with an identical constant fixed property, owing to short-term economic stimulations. In contrast, the cash and loans are dynamic items, especially the latter reflects the debt accumulation of the real sector.

3. The balance sheet of the bank is most complicated. The loans and interbank loans are claims against its debtors in the firm and bank sector respectively. The bank's total reserves consist of a liquidity buffer, required reserves, and loanable funds. The liquidity buffer is to meet the LCR requirement; and the required reserves, which are the fraction of the deposits that the central bank requires the bank to hold. The loanable funds are the remaining part of the bank's total reserves available to lend out to the firms without limit. The deposits and interbank liabilities are the bank's debts arising through the deposit market and interbank market.

As an overview of the model, at first, we depict this artificial economy world on macro-level so as to get a whole picture in advance, instead of excessively sinking into the massive details. In Figure 1, we obviously describe the transactions between any two sectors (the banks and firms, banks and households, firms and households). The three boxes marked BA, HH, and FI stands for the bank, household, and firm sector respectively. The arrow between two boxes represents a type of economic behavior between two individual agents of the two sectors. The arrow inside the banking system represents the interbank lending.

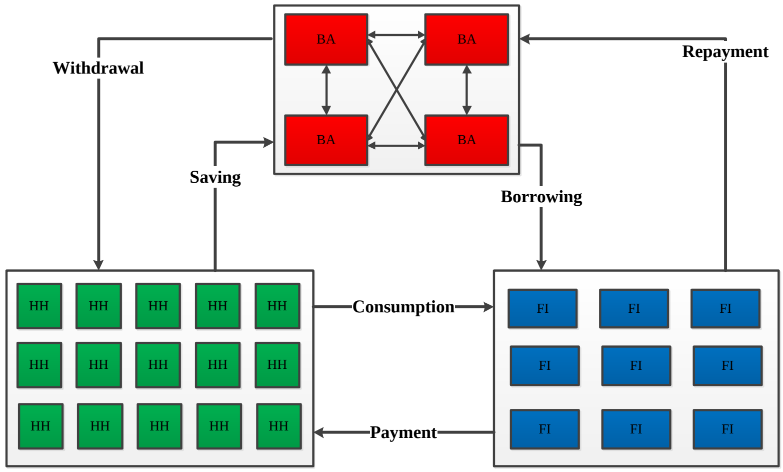

Figure 1: Each arrow indicates a specific behavior, and the direction of it represents that of the money flow.

3.3 The matching mechanism

Owing to the decentralized matching characteristic of ACE model, only when two agents matching together can the corresponding interaction take place. The way to match them from the two sectors probably produces observable effects on outcomes.

In our model, we set two agents are randomly and independently chosen in the two corresponding sectors to form a pair. Even though these pairs are constructed by same matching protocol, one essential distinction divides them into two subgroups in terms of the duration of a pair, whose effects cannot be overlooked. One type is long-term relationship that is fixed from the very beginning of the simulation and does not expire unless one of them failed, the depositor-bank relationship and employment relationship belonging to this type. The other is short-term interaction comprising the borrowing and consumption. As for them, the two agents are matched just before the interaction and disconnected as long as the interaction accomplished. Having matched the agents, we explicitly model the interactions between the coupled agents. For each single transaction, an interaction is equivalent to the corresponding cash flow given by the agents' behavior. Besides, we assume that every transaction between two agents must make use of cash. Sometimes, this requirement is known as "cash in advance" constraint, firstly proposed by Clower (1967) and developed by Lucas (1984, 1980); Lucas and Stokey (1987, 1983).

Table 2: The sequence of events

	Household	Bank	Firm
1			$+$ Incomes from the last period Y_t
2	$+$ Labor incomes W_t		$-$ Employees' wages W_t
3		$+$ Repayments	$-$ Repayments
4		Interbank repayments	
5			Plan the desired investments I_t^d
6		Build up the liquidity buffers according to the LCR	
7		$-$ Loans	$+$ Loans
8	Plan consumption (place orders)		Production
9	$+$ Withdrawals	$-$ Withdrawals	
10	$-$ Consumption C_t^r		$+$ Consumption C_t^r
11	$+/-$ Update wealth:$D_t^h = \beta A_t^h$	$-/+$ Withdrawals/Savings	
12		Interbank borrowing/lending	

Driven by this matching process, four markets emerge in the economy: the credit market, deposit market, goods market, and interbank market. All of them endogenously organize and evolve.

3.4 The sequence of events

The sequence of the events occurring in each period runs is illustrated by Table 2. Note that all sources of funds (inflows) take a plus sign, while the uses of these funds (outflows) take a minus sign. Now we expound Table 2 in detail.

1, Firms receive incomes Y_t consisting of two parts: the investment and consumption realized from the last period,

$$Y_t = C_{t-1}^r + I_{t-1}^r. \tag{2}$$

2, After receiving the incomes, the firms must firstly pay wages to its employees:

$$W_t = \lambda Y_t, \tag{3}$$

where W_t are wages, and the $\lambda \in (0,1)$ is the parameter representing the wage share in our model. The income distributed uniformly for each employees, which is not important to our model.

3, In every period, the firms have to repay its debts to those banks, its creditors. We assume all of the loans banks granted are fully amortizing loans with the same maturity standing by ρ. According to the same maturity of debts, the periodic repayment flow from the firms is calculated as

$$DR_t = \frac{L_t}{\rho}, \tag{4}$$

where L_t is the total outstanding debts of the firms. A firm goes bankrupt as long as one loan cannot be paid off at the end of the maturity term. Therefore, it is vital for the firms to set the priority in repayments. In order to protect itself against bankruptcy, the firms do its best to pay off the debts due in present period, and repay the debts due in $t+1$ period, then due in $t+2$ period, etc. until the firm's currency has been dried up. Therefore, it is possible that the firms cannot maintain the installments of lower priority debts. That is to say, the firms have the options not to repay the loans following the amortization schedule, but prepayment is not allowed. In contrast, you can simply find that the sequence of repayments among the individual firms is non-essential, so they repay their debts one by one following a fixed sequence in each period. If a firm has gone bankrupt, its workers lose their jobs and become unemployed. We give a fixed job finding rate in our simulation, i.e., someone who is unemployment has a constant probability to find an operating firm to work in each turn.

4, Before launching subsequent actions, the banks have to repay their matured interbank liabilities borrowed in the previous periods. In order to make our model more understandable, we explain this after describing Step 12: the interbank lending and borrowing.

5, At this point, the firms decide the amount of money I_t^d they would like to invest. The I_t^d is defined by the following equation:

$$I_t^d = \eta Y_t + \Pi_t. \tag{5}$$

The investment Equation (5) is composed of two terms, ηY_t and $\Pi_t = Y_t - W_t - DR_t$, the net profits. Where $\eta > 0$ is a parameter, which means that the firms do not accumulate capital, and desire to invest more than their net profits. The firms ask for credit to the banks so as to finance the gaps, which gives the demand for loans. Therefore we define credit demand CC_t^d as

$$CC_t^d = \eta Y_t. \tag{6}$$

Then we rewrite the desired investment as the sum of the net profits and credit demand in order to stress the importance of credit creation:

$$I_t^d = \Pi_t + CC_t^d. \tag{7}$$

6, Before lending to the firms and confronting the withdrawals from the households, the bank is required to build up the liquidity buffer and required reserves. We use buf_t to represent the liquidity buffer that the bank should hold at period t. In our model, the bank's only liquidity asset is the reserves, belonging to the Level 1 assets. In the mean time, we can obtain the total net cash outflows over the next 30 calendar days. The expected outflows originate from the liabilities of the bank consisting of the deposits and the interbank liabilities. The expected inflows are determined by the outstanding loans to the firms and the interbank loans. Therefore,the amount of the liquidity buffer that the bank has to hold:

$$buf_t = \delta \times \text{Total net cash outflows over the next 30 calendar days}, \tag{8}$$

where the total net cash outflows over the next 30 calendar days is given by

$$\begin{aligned} &\text{Total net cash outflows over the next 30 calendar days} \\ &= (\text{run-off rate})\times \text{ deposits + interbank liabilities} \\ &- \min[0.5\times \text{ loan+interbank loans}, 75\% \\ &\qquad \times [(\text{run-off rate})\times \text{ deposits + interbank liabilities}], \end{aligned} \tag{9}$$

and the exogenous parameter δ represents the bank's target liquidity coverage ratio, that is, the bigger the δ, the higher the target level of the liquidity buffer, vice versa.

7, As we have explained above, we assume the firms do not save, and the firms desire to invest more than their profits. In our artificial economy, the only way to fiance this gap is to borrow from the banks. After being coupled, the firm asks for the loan to the bank. The bank's responses to the loan applications depends on its quantity of loanable funds. The loan that the bank can offer to the firm given by

$$CC_t^r = \min[CC_t^d, LF], \tag{10}$$

where LF is the quantity of the bank's loanable funds. As long as a loan granted, the firm receives a certain amount of money CC_t^r, in the mean time, there is a same decrease in the bank's loanable funds. If $CC_t^r < CC_t^d$ i.e. the firm is left with unfulfilled loan demand and attempts to reach further loan agreements. We assume every firm has three opportunities to realize its loan demand.

8, In this step, it is determined how much each household desires to spend in current period. The household sets the planned consumption as follows:

$$C_t^{ph} = \alpha_1 w_t^h + \alpha_2 (D_t^h + Cu_t^h), \tag{11}$$

where α_1 and α_2 are two parameters standing for the marginal propensities to consume (MPC) with respect to the current income and the wealth respectively. w_t^h is the current income of the household, and Cu_t^h, D_t^h is the cash and deposits of the household at time t respectively. As for the suppliers, the firms produce homogeneous goods, limited by the full capacity output:

$$F(K,N) = A \times N, \tag{12}$$

where N stands for the total number of employees of the firms and with a homogeneous labor productivity A. The household places an order with a firm whose output has not reached the full capacity according to the matching protocol, then the firm only manufactures products according to the orders to avoid involving inventories.

9, Because of the "cash in advance" constraint, some individuals may face a shortage in cash to pay. Therefore, they need to make a cash withdrawal from the bank. If the reserves of the bank cannot cover the withdrawals of its depositors, the bank can issue negotiable debt certificates to cover those excessive withdrawals over its reserves. However, the certificates have to be redeemed at the end of the period through borrowing from other banks in the interbank market, and those certificates cannot be used to trade. If they are not redeemed, the bank will fail, and then each of the claims against it and issued certificates become worthless.

10, At last, the firms receive the realized consumption C_t^r.

11, As the last step of households, the households try to divide their wealth A_t^h to achieve $D_t^h = \beta A_t^h$, $\beta \in [0,1]$ represents the desired share of deposits relative to the wealth. Thus, the households place cash in the bank or make withdrawals from it. When facing a reserves shortage from withdrawals, the bank will issue the same negotiable debt certificates, as we introduced in Step 9.

12, The present step is the most complicated one in these events. In the beginning, each bank calculates the gap between its total reserves and required reserves to decide how many funds to borrow or invest in the interbank market. Accordingly, the banks are divided into two subgroups: the potential lenders and borrowers. Borrowing terminology from complex network, we say the lenders and borrowers construct a bipartite network. The demand for liquidity by a borrower is the sum of the matured interbank liabilities, which have been delayed repayments since Step 3, the issued negotiable debt certificates in Step 9 and 11, and the required reserves deficit. The bank as a borrower fails, and then is removed from our model if it has not yet offset the liquidity shortage at the end of interbank borrowing. Correspondingly, the supply of liquidity by a potential lender is given by

$$\begin{aligned}\text{interbank loanable funds} = confidence \times (&\text{reserves} \\ &- \text{liquidity buffer} - \text{required reserves}).\end{aligned} \tag{13}$$

At the beginning of the recent financial crisis, the functioning of the interbank markets were severely impaired around the world. As the financial crisis deepened in September 2008, the liquidity in the interbank market has further dried up as the banks preferred hoarding cash instead of lending it out even at short maturities (Acharya and Merrouche, 2013; Acharya and Skeie, 2011; Afonso et al., 2011; Allen and Babus, 2007; Ashcraft et al., 2011; Heider et al., 2009). For considering the bank's interbank risk perception factor, in contrast to the loanable funds to the firms, we put an exogenous parameter $confidence$ as the ratio of the liquidity supply in the interbank market to the loanable funds. We set the same mechanism of making loans in the interbank market as the credit market made up of the firms and banks in Step 7, except that every borrower has as many opportunities as possible to raise funds in the interbank market owing to the interbank borrowing as the lender of last resort here (no central bank liquidity facilities). Consequently, this process probably produces various entangled and long-range connections between the banks, in other words, some complicated community structures.

Having described the interbank lending and borrowing, we are back to Step 4: the interbank repayment. In contrast to Step 3, the sequence of repayments among the individual banks is rather subtle to design, for the reason that the sequence directly determines which banks will fail. To overcome this difficulty, we need to employ the methods used to analyse the complex network. For illustrative purposes, we model a simple square interbank network in Figure 2, where the bank 1 claims against the bank 2, the bank 2 claims against the bank 3, the bank 3 claims against the bank 4, and the bank 4 claims against the bank 1. We assume only the bank 1 possesses sufficient liquidity to repay its matured debts, the other three banks are not able to do this by their own liquidity. If the sequence: $4 \rightarrow 3 \rightarrow 2 \rightarrow 1$ causing the bank 4, 3, and 2 fail owing to liquidity shortage; yet the banking system has not initiated repayments in fact. If we just reverse the sequence, the three banks may receive the sufficient repayments and then survive.

In the network, paying off a debt means cutting an edge between the two banks. Thus, on the other hierarchy, the different arrangements of the repayments among the banks mean reducing the different types of communities. Furthermore, a series of recent works (Squartini and Garlaschelli, 2011; Squartini et al., 2013a,b) have found structures and abundances of the communities deeply affect some aspects of the interbank network including the cascading effect, risk contagion, network robustness, and network equilibrium. In this article, we employ the method introduced by Eboli (2010). You can prove that this rule of repayment reduces any type of community to the possible greatest extent in that the method maximizes the quantity of repayments that potentially occur. Actually, the situation we set here scarcely happens, or you can consider this process is an extreme state of realities, and however the realities may plunge into the opposite extremes in stressed scenario. Properly arranging the sequence of repayments in the banking

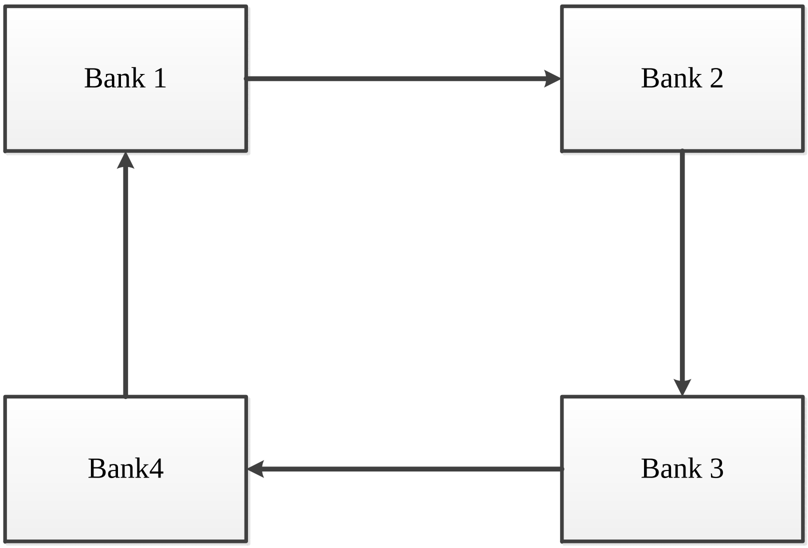

Figure 2: The interbank network is a directed weighted network where the directions represent the creditor-debtor relationships, and the weights refer to the amount of the debts (Bech and Atalay, 2010; Boss et al., 2004; Chinazzi and Fagiolo, 2013; Gai and Kapadia, 2010).

system as a whole probably effectively mitigates the systemic risk by reducing and diminishing the pernicious and invalid communities in the interbank network.

If a bank failed, it pays compensation to the depositors by the remaining reserves, and then repays the outstanding interbank loans.

4 Results and discussion

In this section, we show the simulation results of this model. As we said in Introduction, we are mainly concerned with how the bank sector complying with the LCR affects macroeconomic conditions. Therefore, we track the dynamic paths of meaningful macroeconomic variables. Table 3 shows the parameter settings of the simulation. The initial conditions are defined as follows: the cash $Cu_0^h \sim N(30, (\frac{10}{3})^2)$ and deposits $D_0^h \sim N(80, (\frac{10}{3})^2)$; meanwhile, each bank holds the reserves equal to the amount of deposits. The employment and depositor-bank relationships have been built.

Neither a loan nor an interbank loan exists at the beginning of the simulation. Taking advantage of the balance sheet approach, we can extract the information of each agent's balance sheet at each period, and aggregate the respective items on the individual balance sheets so as to acquire the macro-level variables. We present the main macroeconomic indicators varying with time in the scenario of holding the liquidity buffers to comply with the LCR. When initializing the simulation, we

Table 3: Parameter settings

Description	Symbol	Value
Number of households	HHs	120
Number of banks	BAs	20
Number of firms	FIs	30
MPC with respect to current income	α_1	0.25
MPC with respect to wealth	α_2	0.25
The ratio of deposits to wealth	β	0.7
Job finding rate	ν	0.1
Wage share	λ	0.5
Loan maturity	ρ_f	5
Propensity to invest	η	0.42
Labor productivity	A	30
Interbank loan maturity	ρ_b	3
Required reserve ratio	rr	0.13
Confidence	cf	1.0

set that the target LCR of every bank is 1, and then the system approaches a steady state. During the steady state, we introduce an exogenous shock by raising the value of the LCR. As we have mentioned previously, it means that the bank has a higher target LCR and intends to hold a larger liquidity buffer to protect against the penalties for breaking the requirement. This shock can be considered as a response to the liquidity shortages or stressful economic conditions. However, this shock may lead to triggering a self-reinforcing feedback process. In order to emphasize the effects of the feedback, we provide the contrasts between the feedback effects resulted from the LCR and the benchmark scenario in which the bank constantly holds an average buffer of the actual buffers of the 30 periods from the time point of increasing the LCR, i.e., the feedback process is eliminated, ceteris paribus.

Figure 3 presents typical time series path of the aggregate liquidity buffer of the bank sector. From the beginning of the simulation, the economic system tends to a steady state. During the steady state, we abruptly raise all the banks' target liquidity buffers as a shock to the banking system at 100th period. After then, you can obviously find that the buffer of the LCR climbs up followed by tending to flatten out for a short while, then picks up further, etc., which reflects a typical self-reinforcing feedback process. While the buffer rising up, the aggregate loanable funds continuously diminish so that the credit provided by the banking system reduces accordingly. This result can be understood as follows. Since we assume that borrowing from the banks is the only way to obtain external funds for firms, the reduction of credit supply caused by the shock forces the firms to cut the investments. However, the knock-on effects continue, the incomes of the firms drop

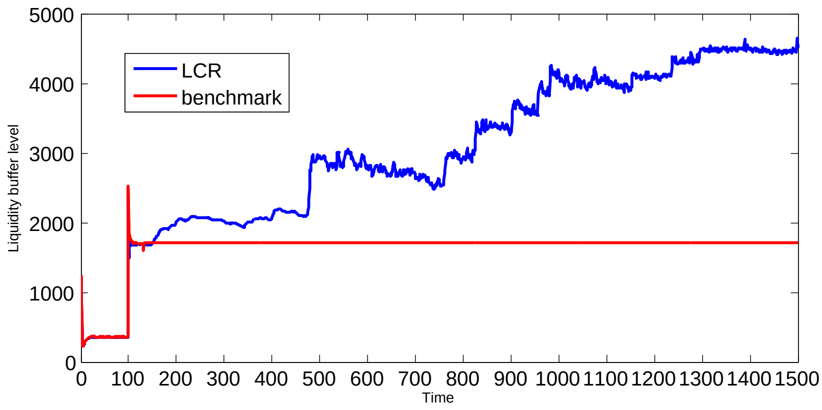

Figure 3: The banks' aggregate liquidity buffer level

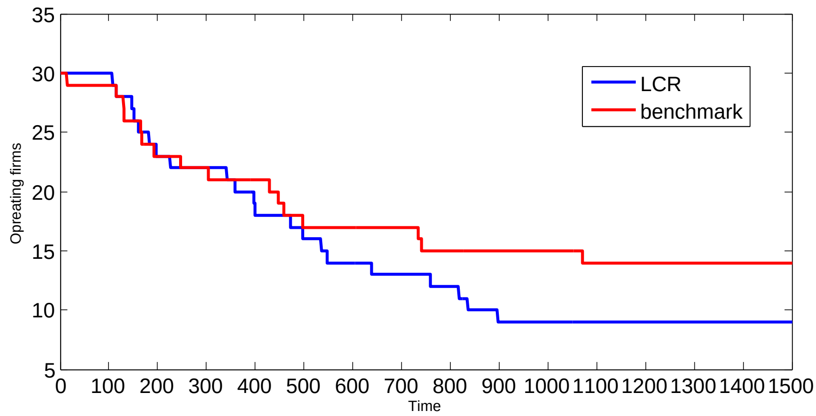

Figure 4: The number of operating firms over time

in the next period on account of the previous investment reduction. In this recession, the firms have to be subject to higher bankruptcy risk as the firms' decreasing incomes weaken the capabilities of paying off their matured debts. As illustrated in Figure 4, in the recession, the firms go bankrupt more frequently and a few waves of bankruptcies appear, which generates a noticeable gap between the two scenarios. Here are the key points for realizing the feedback process: as long as a firm has been bankrupt, the creditors have to charge off the outstanding loans to the firm because any future repayment flows from it cannot be achieved, which implies an unexpected rises in the banks' total net cash outflows. Hence, they have to hold a larger liquidity buffer in order to satisfy the LCR requirement. Consequently, the quantity of loanable funds as well as credit supply further declines. This is clearly illustrated by the aggregate investment in Figure 5 and the amount of credit creation at each period in Figure 6: both of the variables in the LCR scenario are obviously lower than those in the benchmark case.

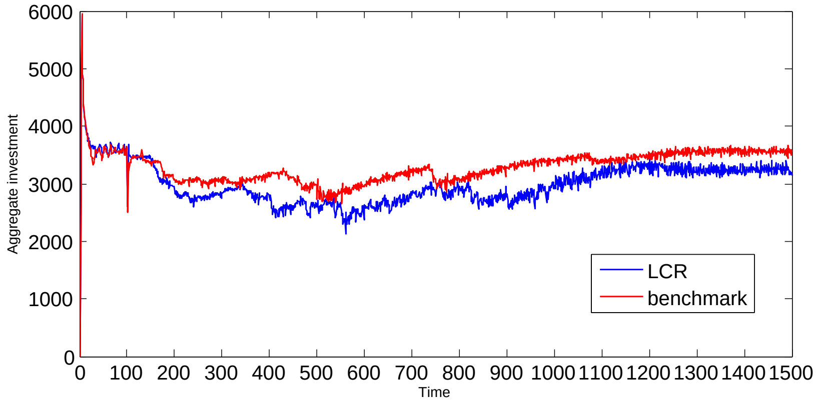

Figure 5: The simulation path of aggregate investment

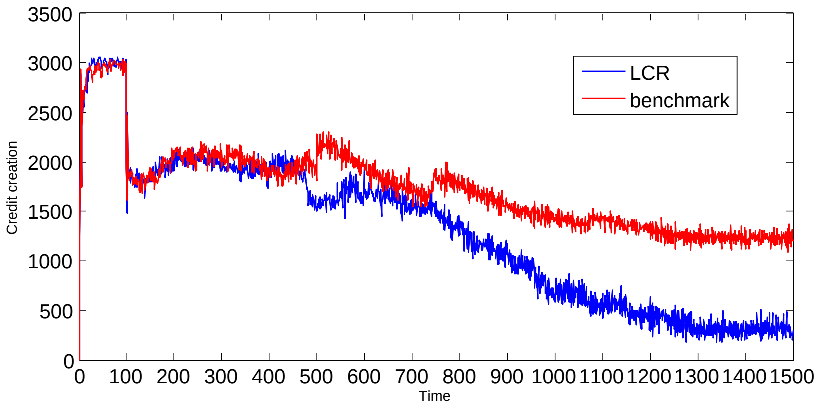

Figure 6: The dynamics of credit creation

The rise in unemployment caused by the bankruptcies leads to a decrease in aggregate supply until they are reemployed. As the firms go bankrupt, the unemployment is sharply increasing during these periods; and the peak is reached, as displayed in Figure 7. In the meantime, according to the job finding rate, the economy matches the laid-off workers and the operating firms. It is worth noting that the reemployment is the main factor to drive the economic recovery by rasing the aggregate output. Thus, after reaching the cycle trough, the economy starts to recover, and the job finding rate significantly influences the severity of the recession and the starting point of the recovery.

We now summarize the feedback process, a contraction in the bank credit supply reduces the aggregate demand; the weakened aggregate demand results in the indebted firms with a higher probability of bankruptcy. The bad loans as a result of the bankruptcy causes the banks that made these loans have to further restrict credit supply so as to reach the LCR compliance.

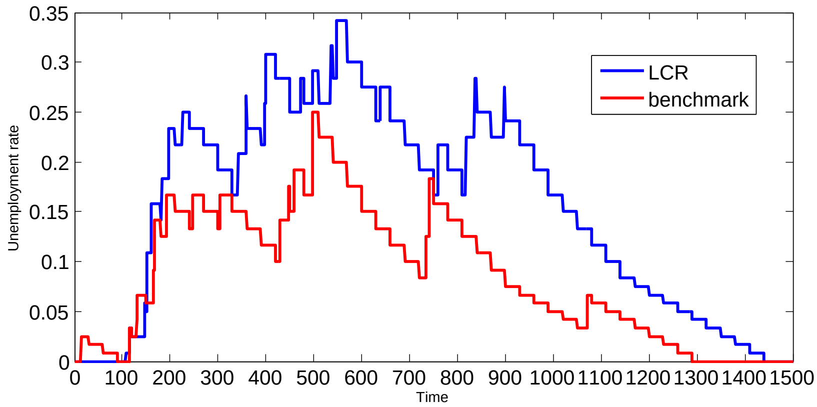

Figure 7: Time evolution of unemployment rate

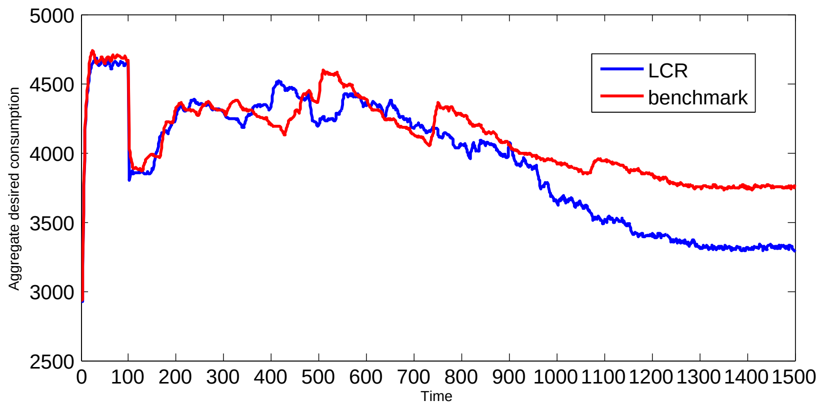

Figure 8: The simulation path of aggregate desired consumption

Compared to the investments, the desired consumption expenditure exhibits very different features. Figure 8 depicts the household desired consumption; instead of a cyclical pattern like the fluctuations of investments (see Figure 5), the gap between the two scenarios continuously widens. This evidence deserves a further scrutiny. Affected by the falls in both the current income and wealth, the consumption expenses decrease (see Eq. (11)); nevertheless, the decrease in wealth generates increasingly stronger effects on reduction in the consumption over time. At the microeconomic level, individuals receiving lower wages as a result of lower incomes of the firms causes accumulating less wealth in the LCR scenario than in the benchmark. Consequently, with the evolution of the economy, a huge gap between the two accumulated wealths in the two scenarios dominates the difference of the household consumption expenditures. However, at macroeconomic level, we provide another perspective to understand this phenomenon based on the M2 monetary aggregate, which represents the aggregate wealth. Figure 9 depicts the

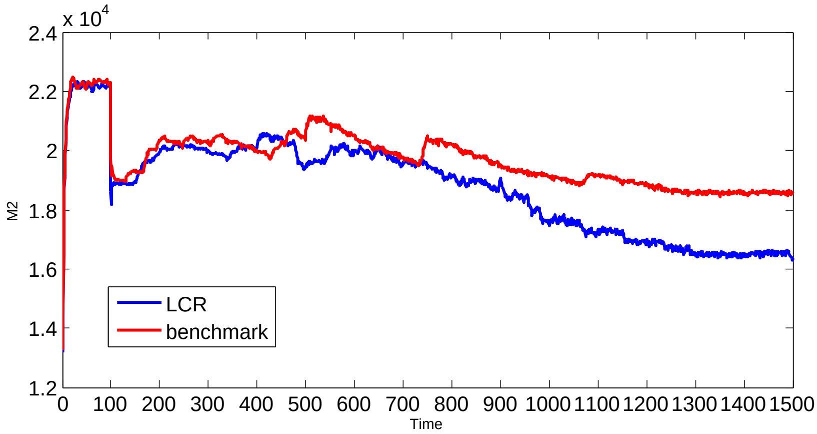

Figure 9: The dynamics of M2

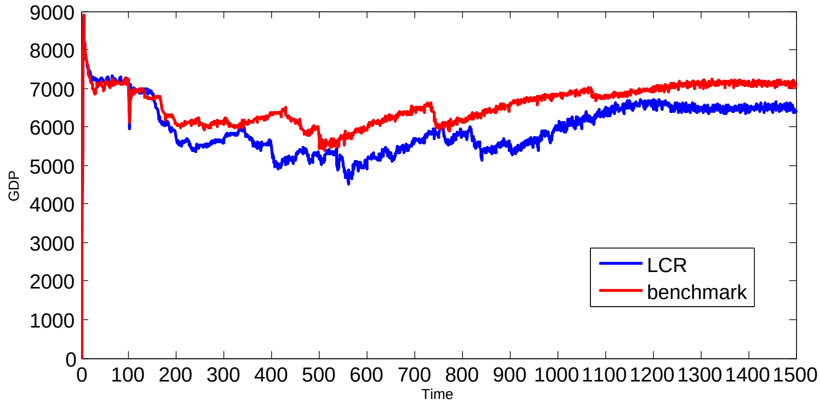

Figure 10: The simulation path of GDP

dynamics of the M2 monetary aggregate consisting of the currency and deposits related to the two scenarios. Owing to the stock-flow consistency, the change in the monetary aggregate is consistent with the net amount of credit creation at each period. Therefore, the gap of the monetary aggregates accumulates from the difference of the two credit creation processes (see Figure 6). The sum of the investment and consumption is the GDP presented in Figure 10.

Similarly, there is another thread to understand the fact presented in Figure 10, called the quantity theory of money introduced by Fisher (1922). In light of this, we provide an explanation so as to feature the function of the monetary aggregate by using equation of exchange, i.e., $P \times Y = M \times V$, which manifests the link between nominal GDP $P \times Y$ and the total quantity of money M by introducing the concept of the velocity of money V. In line with this thread, the obvious difference of M2 between the two cases contributes to the GDP gap.

5 Conclusions

After the recent global financial crisis, a sharply increasing attention has been devoted to cope with the risk originating from the financial sector and design proper bank regulations and requirements. The liquidity requirement is proposed for the first time by the Basel III accord, representing the most important international response to the recent financial crisis. Before our research, a great effort has been done in order to understand and assess the macroeconomic effects of different regulatory instruments desiring to mitigate the individual portfolio risk or systemic risk of the financial sector. The methodologies that most of them used are based on current economic models, especially the DSGE approach.

Compared to current economic models, we build a balance sheet based model to discuss this topic. It is our core question to answer in this work what are the impacts of this new liquidity requirement on macroeconomic conditions? We uncover a potential feedback process triggered by the new regulation. Although, as we know, there is a real danger that the LCR reduces the credit supply of banking systems, leading to dampening the economic activity. However, in our paper, the interesting result is that the liquidity buffer complying with the liquidity coverage requirement may cause a self-reinforcing feedback process between the bank and real sector. In the stressed scenario, the bank raises the target LCR leading to the decrease in loanable funds. Hence the feedback process begins: the decline in the credit supply restricts credit creation; and then reduces both the investment and consumption. Consequently, the decline in aggregate demand induces that some of the firms fail to pay off the debts. if the defaults occurred, the firms go bankrupt. Each firm's bankruptcy causes its creditors, the banks that granted those bad loans, bear the losses. As long as the bad loans are charged off, i.e., the expected repayments are impossible to flow into the banks; they are forced to hold more liquidity buffers once again under the LCR regulation, as results in a further decline in the credit supply.

In this feedback loop, while the aggregate level of liquidity buffer continually rises, the aggregate demand continually decreases, and the increasing number of firms fail. After this self-reinforcing feedback process, the economy settles in a new equilibrium. From the initial equilibrium to the new equilibrium, the economy experiences a recession.

Indeed, our model simulates the modern credit-driven economy, where the core feature is that net changes in the level of debt drive the economy's aggregate demand so that the banking system as the source of credit definitely plays a crucial role in macroeconomic analysis (Bernardo and Campiglio, 2014; Keen, 2014, 2012). Furthermore, our results indicate a potential risk hidden in the kind of bank regulation like the LCR, which would offer the policymakers a suggestion that bank regulation should consider the bank's special externalities of affecting the other sectors in the economic system.

Acknowledgements: We are very grateful to Prof.Yougui Wang, for extremely helpful discussions and suggestions.

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