Economic Modelling 114 (2022) 105916

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.journals.elsevier.com/economic-modelling

A reformulation of the bank lending channel under multiple prudential regulations

Wanting Xiong [a], Yougui Wang [b,*]

[a] Division of Global Macroeconomics and Center for Development Research, Institute of World Economics and Politics, Chinese Academy of Social Sciences, No. 5 Jianguomennei Street, Beijing, 100732, PR China

[b] School of Systems Science, Beijing Normal University, No. 19 Xinjiekouwai Street, Beijing, 100875, PR China

ARTICLE INFO

JEL classification:
E51
E52
G21
G28
G18
E60

Keywords:
Bank lending channel
Basel III
Quantitative monetary policy
Credit creation
Bank regulation

ABSTRACT

The Basel-III accord introduced multiple prudential regulations, sparking concerns that their simultaneous imposition may have unexpected effects on bank lending and its response to monetary shocks. This paper reformulates the bank lending channel (BLC) from a credit creation perspective and examines its changes under different prudential regulations. The traditional BLC predicts an increase in bank lending in response to expanding reserves. We find that such a relation only holds when liquidity requirements constrain banks. When capital requirements become binding and raising new capital is not an option, a reserve expansion may have no effect or may adversely impact bank lending. The simultaneous imposition of multiple regulations complicates the BLC by making it a nonlinear and non-monotonic process, with a strong dependence on bank-specific characteristics and the underlying economic condition. Prudential regulations may hinder the effectiveness of quantitative monetary operations, especially during financial distress.

1. Introduction

Rapid changes in monetary policy and prudential regulations have arisen in recent years. On the one hand, quantitative monetary instruments have been implemented with unprecedented scale, yet the growth of bank credit has been sluggish (Goodhart, 2015; Orlowski, 2015; Borio and Gambacorta, 2017; Williamson, 2017). Surprisingly, despite an enormous quantity of reserves, the banking system still suffered from recurrent liquidity crises, such as the unexpectedly large spikes in the US repo markets in September 2019 and the Covid-19 induced “dash for cash” in March 2020 (Acharya and Rajan, 2022). On the other hand, prudential regulations have been moving from a somewhat “uni-polar” regime centering around capital requirements to a “multi-polar” regime with multiple regulations simultaneously at play (Haldane, 2015; Borio et al., 2020). These changes induce two concerns. One is the potential cross-purposes of monetary policy and prudential regulations, because both operate through the banking system but are oriented by different objectives (Forbes et al., 2017; Djatche and Joslem, 2021). The other relates to the potential costs of more complicated prudential regulations, especially from unintended interactions among different regulations that hinder or reinforce each other (Allen et al., 2012; Haldane, 2015; Haldane and Neumann, 2016; Buckmann et al., 2021).

The Basel-III accord on banking supervision is a best example for the complexity of the multi-polar prudential framework (BCBS, 2010). The Basel-III accord significantly enhanced the original risk-based capital adequacy ratio (CAR) regulation by requesting a significant rise in the minimum requirement. It also added two capital buffers, one for systemically important banks and the other for a countercyclical purpose buffer. In addition to these risk-based capital requirements, banks must conform to the leverage ratio (LR) regulation. The LR requirement uses a non-risk-based metric for capital adequacy, designed to avoid risk measurement and model design errors. Additionally, the Basel-III accord also introduced two liquidity regulations. One is the liquidity coverage ratio (LCR) requirement, designed to enhance the bank’s resilience against short-term liquidity stress.

* Corresponding author.
E-mail address: ygwang@bnu.edu.cn (Y. Wang).

https://doi.org/10.1016/j.econmod.2022.105916
Received 3 September 2021; Received in revised form 20 May 2022; Accepted 27 May 2022
Available online 3 June 2022

The worldwide endorsement of the Basel-III accord has made it imperative for policymakers to understand how each regulation operates by itself, how one regulation interacts with another to form collective economic consequences, and how to coordinate prudential regulations with monetary policy. This study aims to address these questions by employing a bank-centered accounting model to examine the effects of multiple prudential constraints on the transmission mechanism of monetary policy via the banking system. In particular, we investigate the BLC, a traditional bank-based transmission channel, and focus on the transmission of quantitative monetary shocks. While quantitative monetary instruments are more frequently used in many economies with low or even negative interest rates, their transmission mechanism and effectiveness are much less studied in comparison to the extensive literature on the pass-through of interest rate policies.

This paper connects to three strands of literature. First, it builds on the extensive literature related to the BLC. In the traditional BLC story (Bernanke and Blinder, 1988; Kashyap and Stein, 1994; Kishan and Opiela, 2000), a central bank changes the level of reserves by conducting open market operations or adjusting the reserve requirement. This monetary shock first affects the level of reservable deposits,[1] then propagates to the bank loan supply and eventually influences aggregate demand. Despite the comprehensive acknowledgment of this story, recent studies have pointed out several fallacies in its assertions. To start with, the causality of deposits driving loans should be reversed because commercial banks create deposits by granting loans (Disyatat, 2008; McLeay et al., 2014; Werner, 2014). Moreover, the role of reserve requirement as a binding constraint on bank lending has attenuated in many countries, especially after the massive expansion of bank reserves since the 2008 financial crisis (Carpenter and Demiralp, 2012; Fullwiler and Scott, 2012). Additionally, empirical studies have been questioning the effectiveness of this channel, especially in times of large reserves (Gambacorta and Marques-Ibanez, 2011; Martin et al., 2016; Albertazzi et al., 2021).

These concerns have inspired several attempts to rethink the causal links from monetary shocks to the changes in bank lending, including a modified BLC formulation in Disyatat (2011) and a bank deposit channel proposed by Drechsler et al. (2017). We complement this line of work by examining the roles of multiple prudential regulations. We include three prudential regulations in the model to account for liquidity and capital requirements: the CAR, the LR, and the LCR. Additionally, our BLC reformulation builds on the credit creation theory of banking (CCT), which contrasts the intermediary theory of banking by emphasizing the proactive role of banks as credit creators (Jakab and Kumhof, 2015; Angeles, 2019). We put CCT in the context of the BLC and reformulate the causal links in the traditional story. Several other studies use CCT to study the money creation process and the determinants of aggregate money supply (Li et al., 2017; Xiong and Wang, 2018; Xiong et al., 2020; Xing et al., 2020; Li and Wang, 2020). This work differs from these previous studies by focusing on the asset side of the bank (loans) rather than its liability side (deposits).

Second, this paper adds to the growing strand of literature concerning the interactions and compound effects of multiple prudential regulations. One common way to evaluate the effects of Basel-III regulations is to construct a complicated general equilibrium model, impose all concerned regulations at once, and examine their collective impacts on economic growth or social welfare (Goodhart et al., 2013; Covas and Driscoll, 2014; Krug et al., 2015; Boissay and Collard, 2016; Fender and Lewrick, 2016; Buckmann et al., 2021). However, due to the complexity of these models, it is often too complicated to identify the transmission channels of different regulations, let alone to understand their interactions. Some scholars simplify the analysis by considering fewer regulations. For example, Goel et al. (2017); Mankart et al. (2020) only account for two capital requirements, while Behn, Corrias, and Rola-Janicka (2019a) studies two liquidity requirements. Other scholars consider capital and liquidity regulations but simplify their analysis by focusing on a shorter logic link. These studies abstract from the rest of the economy and focus on how the banking system reacts to the imposition of multiple prudential regulations (Xiong and Wang, 2018; Cecchetti and Kashyap, 2018; Behn, Daminato, and Salleo, 2019b; Xiong et al., 2020; Xing et al., 2020; Carletti et al., 2020; Hodula et al., 2021).

Lastly, this study is closely related to the discussions on the interactions between monetary policy and prudential regulations. Due to this problem's complexity, individual studies can only contribute pieces to the big picture by taking on different angles. For instance, Popoyan et al. (2017) uses an agent-based model to test the effectiveness of different combinations of rule-based monetary policy and macroprudential regulations in reducing macroeconomic instability. Djatche and Joslem (2021) focuses on the effects of monetary policy and prudential regulations on banks' risk-taking behaviors. Forbes et al. (2017) investigates the interactions between unconventional monetary policy and bank regulatory policies from an international dimension by studying their effects on cross-border bank lending. Jacob and Munro (2018) examines the potential trade-offs between monetary policy and the new prudential requirement on the net stable funding ratio. Notwithstanding these efforts, there is more to explore regarding the respective and collective effects of different prudential regulations on specific monetary transmission channels.

This paper contributes to the discussions about the coordination between monetary policy and prudential regulations by taking a three-step investigation into the performance of the BLC under multiple prudential regulations. First, we provide an intuitive explanation for why the imposition of a prudential regulation would affect bank lending behaviors and their responses to monetary shocks. Prudential regulations require the bank to maintain adequate safety buffers against the solvency or liquidity risks associated with credit creation, regardless of liquidity or capital requirements. These constraints form a structural relationship between the bank's lending capacity and its safety buffers. When a particular prudential requirement constrains the bank, an expansionary monetary shock may fail to stimulate more lending if the bank does not have enough safety buffers to guard against additional risks associated with new lending.

Second, we compare the standalone effect of each regulation. We find that the response of bank lending to reserve shocks varies with the binding regulatory constraint imposed upon the bank. The traditional BLC predicts that bank lending should increase after reserve expansions; however, we find this relation may not always be true. In particular, the positive relationship between bank lending and reserves still holds when the LCR requirement constrains the bank. However, if the CAR requirement or the LR requirement becomes the effective binding constraint, an expansionary reserve shock may have no effect or an adverse effect on bank lending.

Third, we examine a more sophisticated case where all three requirements are imposed simultaneously. When multiple requirements are at play, the most stringent constraint determines the bank's lending capacity. Since the effective binding constraint on bank lending varies with bank-specific characteristics and the underlying economic condition, the transmission of quantitative monetary shocks via the BLC under multiple prudential constraints becomes a nonlinear and non-

[1] The association between monetary policy and deposits is generally motivated through two mechanisms. The first is based on the money multiplier story, where the central bank renders effective control of the level of reserves in the banking system, and banks are constrained by a binding reserve requirement(Bernanke and Blinder, 1988; Kashyap and Stein, 2000). In this case, a reduction in reserves reduces reservable deposits because the bank wants to remain above the minimum reserve requirement. The second mechanism relies on portfolio substitution arguments, whereby the central bank's action alters the yields on deposits relative to other assets, which changes the households' preference for deposits (Kishan and Opiela, 2000). Either way, the influence of monetary shocks on bank lending is attributed to a policy-induced change in deposits.

monotonic process. In general, the caveat is that the simultaneous imposition of multiple regulations could hinder the effectiveness of a quantitative monetary policy in boosting bank lending. Our findings support the idea of relaxing prudential constraints during financial distress to enhance the coordination between prudential regulations and monetary policy, as observed during the Covid-19 crisis (BCBS, 2020).

The rest of this paper is organized as follows. Section 2 provides an intuitive interpretation of this work's reformulated BLC. Section 3 sets up the theoretical framework. Section 4 presents the standalone and collective effects of different prudential regulations on bank lending and its response to quantitative monetary shocks. Section 5 concludes.

2. A reformulation of the BLC

This section aims to provide an intuitive explanation for the logic link of the BLC from a credit creation perspective and discuss the roles of prudential regulations in this process. First, we revisit the theoretical premises in the traditional BLC and explain why its causality needs a reformulation. Second, we examine the roles of prudential regulations in bank credit creation. Third, we present an alternative causality for the operation of the BLC. Fourth, we compare the reformulated BLC with other related monetary transmission channels.

The traditional story of the BLC is premised on three propositions. First, monetary shocks can effectively influence the level of bank deposits. Second, bank lending is driven by deposits. Third, bank loans are not substitutable for at least some borrowers. While the third proposition is generally accepted (Kashyap and Stein, 2000), there have been considerable disputes regarding the first two propositions. To begin with, questions are raised about the association between monetary shocks and the level of deposits. As expounded in the textbook (Mankiw, 2014), there is a mechanical link between the level of reserves and that of bank deposits when the bank system is constrained by a binding reserve requirement.

However, a binding reserve requirement assumption is less relevant to modern banking practices, especially in advanced economies. For instance, there is no reserve requirement in Canada, the U.K., Australia, or New Zealand. In the U.S., the reserve requirement is still in force, but the required reserve ratio is much lower and applied to fewer deposits than before (Bernanke, 2007; Carpenter and Demiralp, 2012). More importantly, to facilitate smooth interbank payments and achieve policy rates, reserves are usually supplied non-discretionally to accommodate banks' demands. In addition, due to massive countercyclical monetary expansions during recent crises, the level of reserves in the entire banking system has reached an unprecedented scale. Even if an individual bank faces a shortage of reserves, it can efficiently insulate its loan portfolio from the reserve constraint by replacing reservable deposits with non-reservable liabilities raised from the financial market. In other words, as a result of expanded reserves and a reduced proportion of reservable deposits in bank liabilities, the constraint of the reserve requirement has been significantly less concerning for the modern banking system.

Even if the reserve requirement is of more relevance in certain economies, the proposition of deposits driving loans is also found to be misplaced (Disyatat, 2011). In contrast to the conventional view that banks are merely financial intermediaries who lend out deposited funds, there is a growing consensus on the proactive role of banks in credit and money creation, often referred to as the credit creation theory of banking (Moore, 1988; Palley, 1994; Disyatat, 2011; Keen, 2011; Werner, 2014; Carpenter and Demiralp, 2012). According to this view, deposits are the product of bank lending rather than its prerequisites. When a bank makes a loan, it simply creates a matching deposit in the borrower's bank account without pre-existing deposits.

If holding deposits is not a prerequisite for making loans, then what constrains bank lending? According to McLeay et al. (2014), one of the answers lies in the bank's ability to manage risks and the prudential regulations to which it is subject. To understand this causality, we must examine the consequences of making a new loan. As illustrated in Fig. 1, one consequence is a simultaneous expansion in both loans and deposits. The other consequence is increased exposure to liquidity and solvency risks. The liquidity risk comes from the maturity mismatch between loans and deposits. Usually, the maturity of loans is longer than that of deposits. Therefore, to satisfy the depositor's demand of withdrawal or transfer, the bank cannot rely on illiquid assets, like loans, but has to hold liquid assets, like cash or reserves. The solvency risk is associated with loan defaults. Loans are risky assets that may not be repaid. Whenever there is a loan default, the bank suffers from asset loss. If the loss is large enough, the bank may become insolvent as its capital holdings are depleted.

Banks cope with liquidity and solvency risks in several ways. Regarding solvency risk, banks maintain a sufficient level of capital or draw down their investment in risky assets, as illustrated in Fig. 2(a). As shown in Fig. 2(b), banks manage the liquidity risk by holding a buffer of liquid assets (usually also with high quality) or by increasing the share of stable liabilities. In other words, high-quality liquid assets, like reserves, can be regarded as the safety buffer against liquidity risks, and bank capital can be viewed as the safety buffer against solvency risks. Theoretically, banks should be self-motivated to hold the buffers of liquid assets and bank capital in reasonable sizes to control these risks. However, banks are profit-driven. They are often prone to underestimate their risk exposure and reduce their holdings of liquid assets and bank capital to enlarge the interest margins, especially when the collective expectation of the market is generally positive during economic booms. As manifested in the most recent crisis, the banking system's destabilizing nature implements proactive prudential regulations, a necessary procedure to improve the banking system's health and reduce the possibility of future crisis. Therefore, the Basel-III accord came up with different prudential regulations to guard against various risks. The LCR regulation, for instance, requires the bank to hold enough high-quality

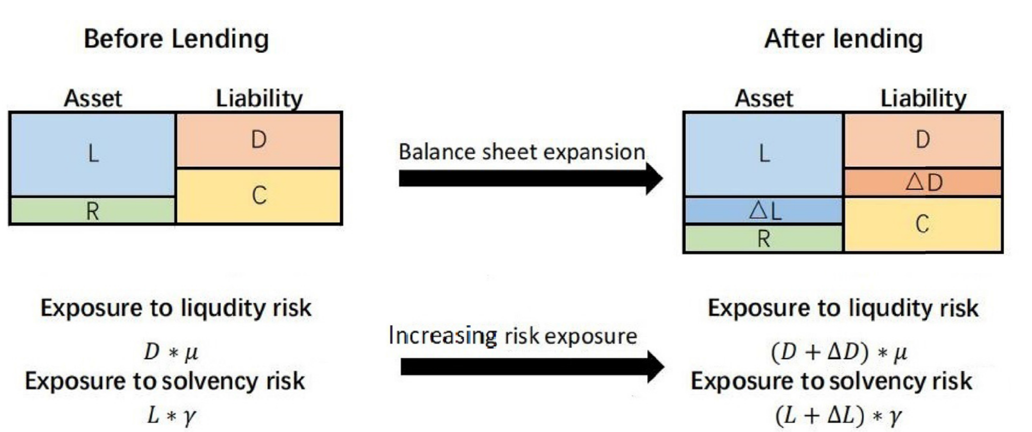

Fig. 1. An illustration for the consequences of bank lending. The stocks of loans, reserves, deposits and capital are indicated respectively by L, R, D and C. μ denotes the run-off rate of deposits due to customer withdrawal, transfer, or other reasons. γ denotes the probability of loan default. **Implications:** The act of bank lending has two consequences. One is a simultaneous and equivalent expansion of the bank's balance sheet on both sides. Although bank lending increases the stocks of loans and deposits, it does not change reserves and capital level. The other is an increase in its exposure to liquidity and solvency risks.

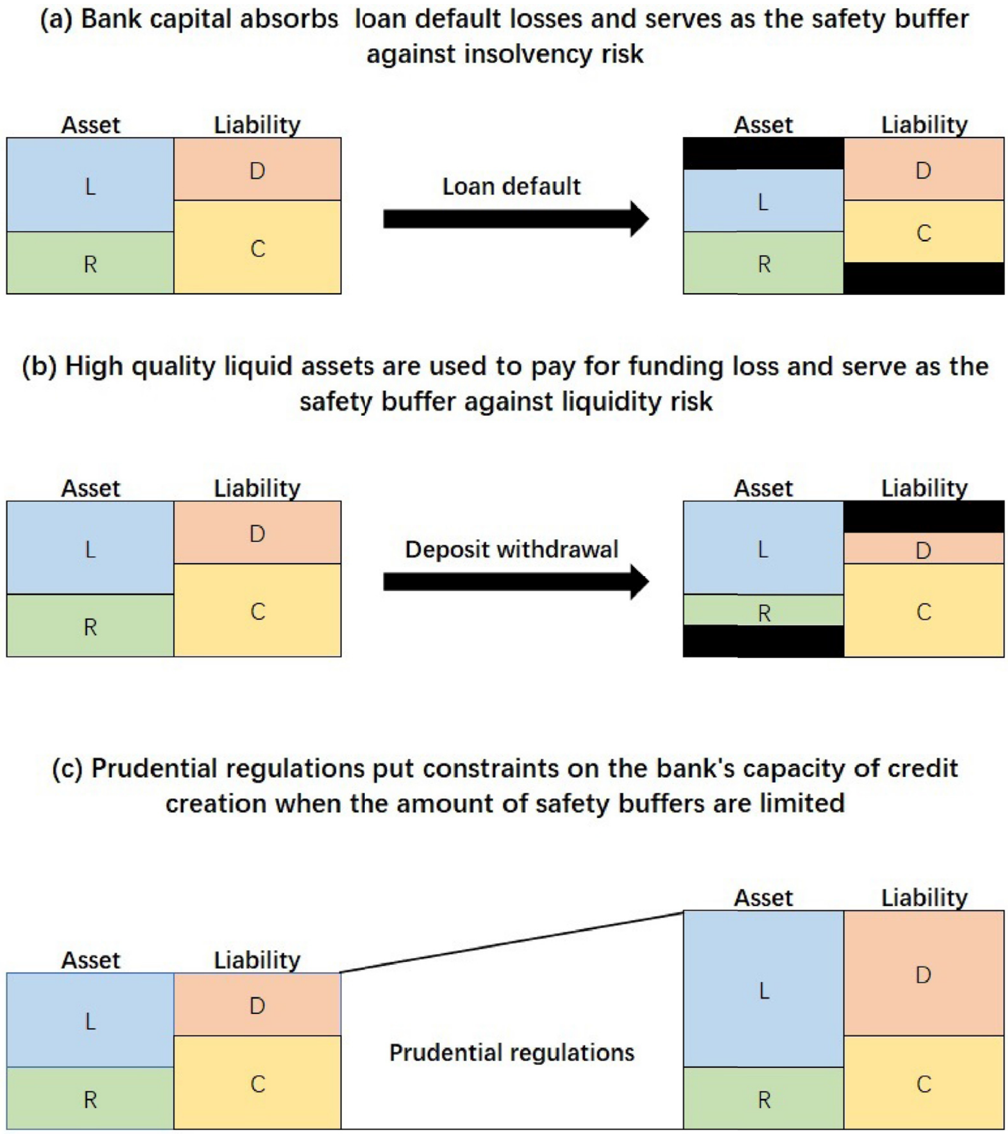

Fig. 2. An illustration for how prudential regulations put constraints on a bank's credit creation capacity. Notations are the same as those in Fig. 1. Black boxes indicate a reduction in the corresponding stock.

liquid assets (HQLA) as a safety buffer against funding loss during times of stress. The CAR regulation demands an adequate level of bank capital as the safety buffer against the potential default losses associated with its asset portfolio. The LR regulation focuses on bank capital adequacy but differs from the CAR regulation in defining how much capital is enough.

Notwithstanding the differences in their aims and designs, the prudential regulations of LCR, CAR, and LR, in essence, all engender a limit on the bank's credit supply concerning certain types of safety buffers, given its risk exposure in the current economic state. As demonstrated in Fig. 2(c), the imposition of these prudential regulations limits the maximum amount of credit the bank can create by requiring the banks to hold an adequate level of safety buffers in proportion to their total risk exposure. For the overall banking system, the level of safety buffers is usually limited. Unlike loans and deposits, safety buffers like reserves and capital do not increase with new bank lending. Additionally, it is usually challenging for banks to proactively increase the safety buffers, at least within a short period and when the overall economic condition is weak. On the one hand, for the overall banking system, the central bank typically dictates the level of reserves. The act of deposit transfer or other interbank transactions may affect the reserves holdings for individual banks, but they do not change the total level of reserves in the entire banking system. On the other hand, for the level of bank capital to increase, a bank must either accumulate retained earnings and cut dividends or issue new stocks in the bank equity market. None of these approaches are easy and desirable for profit maximization purposes. Accumulating more retained earnings is time-consuming and may hurt the bank's profitability performance, which further hinders its future equity financing opportunity. Other options rely on the financial market condition, which entails significant marketing, legal, and processing costs. Consequently, banks usually have great reluctance or difficulty in increasing bank capital. Due to the limitation of safety buffer and the rising risk exposure associated with credit expansion, prudential regulations have a constraining effect on bank lending. Empirical evidence supports this assertion that banks respond to tighter capital requirements by reducing lending in the short run and increasing capital holdings in the long run (Jackson, 1999; VanHoose, 2007, 2008).

Having explained the role of prudential regulations in constraining bank lending, we present an alternative BLC story from the credit creation perspective and discuss the role of prudential regulations in the BLC. As in the traditional BLC, an expansionary monetary shock would increase the level of reserves in the banking system, which can be used

Table 1
A comparison of the traditional BLC, this paper's reformulated BLC, the reformulated BLC in Disyatat (2011), and the bank capital channel.

	Traditional BLC	Reformulated BLC in the current paper	Refined BLC in Disyatat (2011)	Bank capital channel
The role of banks	Financial intermediary	Credit creator	Credit creator	Not specified
Regulatory constraint	Reserve requirement	Multiple prudential regulations	Not necessary	Capital regulation
Type of monetary shocks	Changes in the level of reserves or in the policy rate	Changes in the level of reserves	Changes in the policy rate	Changes in the policy rate
Causality	Monetary shock ⇒ Changes in level of deposits ⇒ Changes in the supply of loans	Monetary shock ⇒ Changes in the level of safety buffer ⇒ Changes in the capacity of credit creation ⇒ Changes in the supply of loans	Monetary shock ⇒ Changes in the deposit rate ⇒ Changes in the external financing premium of the bank ⇒ Changes in the loan rate ⇒ Changes in the supply of loans	Monetary shock ⇒ Changes in the interest margin ⇒ Changes in the level of capital ⇒ Changes in the cost of making loans ⇒ Changes in the supply of loans

as safety buffers against liquidity risks. The imposition of prudential regulations gives rise to a mechanical relation between the level of safety buffers and the maximum level of loans the bank can make (i.e., credit creation capacity). Therefore, an increase in safety buffers can boost the bank's credit creation capacity and eventually lead to more new lending. There are three distinctive features of this study's reformulated BLC. First, deposits are not the prerequisite for loans; instead, both deposits and loans increase (decrease) with a new loan (repayment). Second, there is a mechanical link between the bank's credit creation capacity and the corresponding safety buffers in the system from the imposition of prudential regulations or out of the bank's own risk management concerns. Such a link varies with the regulation design. Third, quantitative monetary shocks impact the bank's credit creation capacity by affecting the level of safety buffers.

To better position the current paper in the literature, it would be helpful to compare our BLC reformulation with other related channels for monetary transmission. Table 1 presents a thorough comparison of these channels. The first channel for comparison is the refined BLC proposed by Disyatat (2011). Both works agree with the assertion of loans driving deposits rather than the other way around; however, they place different importance on the nature of the monetary shocks (changes in the interest rate or the reserve quantity) and the banks' response (the quantity or the price of loans). Moreover, while the regulatory constraint on bank credit creation is a necessary condition for the existence of the reformulated BLC in the current analysis, no exogenous regulations are required in Disyatat (2011). The second channel for comparison is the bank capital channel (BCC) proposed by Van den Heuvel (2006). Our reformulated BLC is similar to the BCC in that both channels depend on the constraining effects of prudential regulations on lending; however, they differ from each other in the types of monetary shocks and their effects on bank capital. The BCC starts with a change in the policy rate, which affects the interest margin and then the accumulation of bank capital. Our reformulation focuses on monetary shocks, like quantitative easing, and does not account for changes in capital accumulation due to varying interest margins.

3. The model

To study the impacts of Basel-III regulations on bank credit creation and the BLC of monetary transmission, we adopt a balance sheet approach (Bezemer, 2010, 2012) with emphasis on stock-flow consistency and the loans-driving-deposits perspective. Specifically, we set up a bank-centered model under the KISS principle (Keep It Simple, Stupid) to focus on the response of bank lending to quantitative monetary shocks. Despite being rather parsimonious, the model is equipped with all the necessary elements, and its simplicity allows us to focus on the complexity of the multi-polar prudential framework while maintaining an easy-to-follow reasoning process. A similar analytical approach has been taken by Li et al. (2017); Xiong and Wang (2018); Xiong et al. (2020); Xing et al. (2020).

Table 2
A simplified balance sheet for a representative commercial bank.

Asset	Liability
Reserves (R)	Deposits (D)
Loans (L)	Capital(C)

3.1. Basic setup

The model considers a representative commercial bank whose balance sheet is represented by Table 2. The bank holds two types of assets: reserves (R) and loans (L) with an average risk weight of γ. Its liabilities comprise deposits (D) and capital (C). The accounting identity of total assets and liabilities gives that

$$R + L(t) = D(t) + C. \tag{1}$$

As indicated by the above equation, the stocks of reserves R and capital C are assumed to be exogenous; the stocks of deposits D and loans L are determined endogenously in the credit creation process.

Suppose that the bank only profits on the interest spread between its liabilities and assets, the expression for the profit of the bank is given by

$$\Pi = r_R R + r_L L - r_D D - r_C C, \tag{2}$$

where r_R, r_L, and r_D are, respectively, the interest rates on reserves, loans, and deposits. r_C refers to the cost of capital, such as the dividends to shareholders. Because $D = R + L - C$ and the level of capital and reserves are assumed to be exogenous, we can rewrite the expression for profit as the following function of loans:

$$\Pi = (r_L - r_D)L + (r_R - r_D)R + (r_D - r_C)C. \tag{3}$$

Due to the imposition of prudential regulations, the bank must keep the actual regulatory ratio α_{reg} above the corresponding minimum requirement r_{reg}. As explained in the previous section, expanding bank credit without increasing the safety buffer can reduce the regulatory ratio. In other words, when the actual regulatory ratio approaches its minimum requirement, the level of loans would also reach its maximum value. We refer to this maximum limit as the bank's credit creation capacity and denote it as $L_{\max}$. Therefore, the bank's profit maximization problem under prudential regulation can be written as follows:

$$\max_{L} \ \Pi = (r_L - r_D)L + (r_R - r_D)R + (r_D - r_C)C, \tag{4}$$

$$s.t. \quad L \le L_{\max}. \tag{5}$$

Therefore, with R and C being exogenous and $r_L - r_D > 0$, the bank should operate at the maximum credit creation capacity to maximize its profit. Moreover, the endogenous dynamics of the stocks of loans and deposits are governed by the difference between the new lending flow (LF) and the repayment flow from outstanding loans (RP), i.e.,

$$L(t+1) - L(t) = LF(t) - RP(t), \tag{6}$$

$$D(t+1) - D(t) = LF(t) - RP(t). \tag{7}$$

We assume that all loans are amortized with an average maturity of θ months to determine the flow variables. Consequently, the total repayment flow due at time t for all outstanding loans can be computed as the sum of due repayment for all loans made in the past θ, as follows:

$$RP\,(t) = \begin{cases} 0, t = 1; \\ \sum_{t'=1}^{t-1} \frac{LF(t')}{\theta}, 1 < t < \theta; \\ \sum_{t'=t-\theta}^{t-1} \frac{LF(t')}{\theta}, t \geq \theta. \end{cases} \tag{8}$$

Conversely, the new lending flow[2] is given by

$$LF(t) = RP(t) + \rho(L_{\max} - L(t)), \tag{9}$$

where $L_{\max}$ refers to the maximum level of loans the bank can create, i.e., the bank's credit creation capacity, given the bank's current risk exposure and the constraints of concerned prudential regulations. The parameter $\rho \in [0,1]$ reflects how the bank approaches the maximum limit of credit creation.

The initial condition of the dynamical credit creation process is assumed to be $L(1) = 0, D(1) = R - C$. The stock-flow equilibrium is defined as a stationary state where all stocks and flows are unchanged. Suppose the system reaches such equilibrium at time t^*. Then $\forall t \geq t^*, L(t) = L^*, D(t) = D^*, LF(t) = LF^*, RP(t) = RP^*$, where L^*, D^*, LF^*, and RP^* respectively denote the equilibrium values of the loan stock, the deposit stock, the new lending flow, and the repayment flow. Combining the laws of motion governing the stock-flow consistency in Equations (1), (6) and (7) with the expression of the new lending flow in Equation (9), we prove that the following relations must hold in the equilibrium state,[3]

$$L^* = L_{\max}, \tag{10}$$

$$D^* = R + L^* - C = R + L_{\max} - C, \tag{11}$$

$$LF^* = RP^*, \tag{12}$$

$$LF^* = \frac{2}{1+\theta} L^* = \frac{2}{1+\theta} L_{\max}. \tag{13}$$

Compared with other theoretical works in the literature, our analytical framework has some unique features. First, a bank-centered model does not regard pre-existing deposits as the prerequisite for bank lending. Alternatively, we argue there is a maximum limit on bank credit creation because of the difficulty of increasing the corresponding safety buffer and the rising risk exposure rooted in credit creation. For instance, a bank faces higher liquidity risk when it creates a matching deposit for its borrowers because such deposits can easily leave the bank, yet loans are only paid when they become due. To cope with this potential liquidity problem, the bank must hold sufficient reserves or other HQLA, which do not increase with bank lending like the stocks of loans and deposits. In this sense, the bank's credit creation capacity ($L_{\max}$) is constrained by its ability to manage risk, which fundamentally depends on the actual safety buffers and the market-based or regulation-induced standard for the size of the business these safety buffers can safely support. Consequently, when the banking system maxes out its credit creation capacity (as indicated by Equation (10)), the credit creation process eventually reaches a stock-flow equilibrium.

Second, in contrast to the common neglect or de-emphasis of the repayment behavior, the model associates repayment flow with the size of outstanding loans and their corresponding maturity structure (Equation (8)). In addition, it is presumed that all repayments are reinvested to make new loans (Equation (9)). Note that this does not mean that the bank cannot make new loans without receiving repayments. As long as the bank can manage the additional risk associated with credit expansion (i.e., $L(t) < L_{\max}$), new bank lending can be issued. When the bank does reach the equilibrium of credit creation where it cannot afford more risk given the current level of safety buffer, the speed of revolving existing credit determines the flow of new lending (Equation (12)). As indicated by Equation (13), the bank makes more new lending in the equilibrium state (LF^*) when the average maturity of past loans is shorter (smaller θ). These new loans contribute to aggregate demand by financing expenditures that would otherwise be impossible.

Third, this model complies with the stock-flow consistency principle. Although the model is not a full version stock-flow consistent model with all sectors of the economy, as formalized in Godley and Lavoie (2012), the model has no accounting black holes. This quality is often underappreciated in many works, but it is indispensable to ensure the logical consistency of the subsequent analysis. This feature allows for the possibility of extending the current basic model setting to more complicated stock-flow consistent models, as proposed in Caiani et al. (2016).

3.2. Contents of basel III regulations

Liquidity coverage ratio. The LCR regulation is introduced by Basel III to promote the short-term resilience of a bank's liquidity risk profile by ensuring that it has sufficient high-quality liquid resources to survive a one-month acute stress scenario. The LCR is defined as the ratio of the amount of HQLA to the total net cash outflow (NCOF) over 30 days in distressed conditions. Denote the bank's actual LCR as α_{LCR} and the minimum policy ratio as r_{LCR}. The mathematical expression for the LCR regulation is given by

$$\alpha_{LCR} = \frac{HQLA(t)}{NCOF(t)} \geq r_{LCR}. \tag{14}$$

The minimum liquidity coverage ratio r_{LCR} was initially set to 60% in 2015 and should rise in equal annual steps to 100% on January 1, 2019.

According to the Basel-III accord, assets qualified as HQLA must be of low risk and have easy and immediate convertibility into cash at little or no loss of value. In this model, HQLA only includes reserves, i.e.,

$$HQLA(t) = R. \tag{15}$$

Conversely, the total net cash outflows are defined as the total expected cash outflows (OF) minus total expected cash inflows (IF) up to an aggregate cap of 75% of the total expected cash outflows in the specified stress scenario for the subsequent 30 calendar days, i.e.,

$$NCOF(t) = OF(t) - min\{IF(t), 0.75OF(t)\}. \tag{16}$$

The 75% cap of total expected cash outflows is specified and introduced in Basel III to prevent banks from relying solely on anticipated inflows to meet their liquidity requirement; they must maintain a minimum amount of stock of $HQLA$ equal to 25% of the total cash outflows.

Specifically, 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

[2] Note that here we abstract from the behaviors of borrowers by assuming the demand for loans always exceeds supply. This simplification can also be found in other bank-centered works, such as Furfine (2001); Kopecky and VanHoose (2004). This setting allows us to focus on the BLC of monetary transmission and abstract from the broad credit channel where monetary shocks affect the balance sheet conditions of the borrowers and eventually impact their demand for loans.

[3] More details can be found in Xiong and Wang (2018).

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 expected rates. For simplicity, we assume cash outflows are caused by deposit run and are proportional to the total debt-based financing with a run-off ratio of μ,[4] which is given by

$$OF(t) = \mu D(t). \tag{17}$$

The larger the run-off ratio (μ), the less stable the debt-based funding of the bank becomes. For this reason, hereafter μ also specifies funding stability.

Suppose all loans are made to retail customers. In the stressed condition designed in the Basel-III accord, the bank is assumed to receive all payments within the considered 30-day horizon as the contractual cash inflow and continue to extend loans at 50% of these inflows. Therefore, disregarding interest payments, the total cash inflow should amount to half of the repayment flow, i.e.,

$$IF(t) = 0.5RP(t). \tag{18}$$

Substituting Equations (16) and (17) into Equation (18), we rewrite Equation (16) to obtain the expression for the bank's net cash outflow at month t, which is given by

$$NCOF(t) = \begin{cases} 0.25\mu D(t), & IF(t) \geq 0.75OF(t); \\ \mu D(t) - 0.5RP(t), & IF(t) < 0.75OF(t). \end{cases} \tag{19}$$

By injecting Equations (19) and (15) back to 14 and rearranging the inequation, the requirement of LCR regulation can be restated as follows:

$$r_{LCR} \leq \begin{cases} \dfrac{R}{0.25\mu D(t)}, & IF(t) \geq 0.75OF(t); \\ \dfrac{R}{\mu D(t) - 0.5RP(t)}, & IF(t) < 0.75OF(t). \end{cases} \tag{20}$$

The risk-based capital adequacy ratio. For simplicity, our model does not distinguish the quality of bank capital and assumes all capitals are qualified in calculating the risk-based capital adequacy ratio. Taking α_{CAR} and r_{CAR} respectively as the actual ratio and the minimum policy requirement, we have the following expression for the CAR regulation:

$$\alpha_{CAR} = \frac{C(t)}{RWA(t)} \geq r_{CAR}, \tag{21}$$

where RWA denotes the amount of risk-weighted assets, computed as the product of bank assets and their corresponding risk weights. It takes the following form,

$$RWA(t) = \gamma L(t). \tag{22}$$

The leverage ratio. With the actual leverage ratio and its minimum policy requirement being denoted as α_{LR} and r_{LR} respectively, the LR regulation can be mathematically expressed as

$$\alpha_{LR} = \frac{C(t)}{TA(t)} \geq r_{LR}, \tag{23}$$

where TA represents the amount of total assets, calculated as the sum of reserves and loans in this case, i.e., $TA = L + R$.

4. Results

This section first analyzes the standalone effects of individual regulations in Sec.4. A and then accounts for the collective consequences of the simultaneous imposition of all three prudential regulations in Sec.4.B.

[4] To simplify the analysis, we regard deposits as a general representative for all debt-based financing. In reality, deposit run may have been largely reduced due to the support of deposit insurance policy, while the losses of non-equity financing may mostly come from uninsured deposits or wholesale funding.

4.1. Standalone effect of individual regulation

To compare the standalone effects of different regulations on bank credit creation, we derive the mathematical expression for the credit creation capacity and that for the new bank lending flow under each regulation in the equilibrium state in Section 4.A.1. Based on these expressions, we further investigate the respective determinants of bank credit creation in Section 4.A.2 and how the BLC operates under each regulation in Section 4.A.3.

4.1.1. Equilibrium bank lending under each individual regulation

As indicated by Equations (10) and (14), the credit creation capacity of the bank under the LCR regulation is obtained when the actual LCR of the bank is equal to the minimum LCR requirement, i.e., the equality holds in Equation (14). Specifically, when $IF(t) \geq 0.75OF(t)$, replacing $D(t)$ with $D(t) = R + L(t) - C$ and manipulating the above inequation, we can infer that the LCR puts an upper bound on the level of loans that the bank can create, i.e.,

$$L(t) \leq \left(\frac{4}{\mu r_{LCR}} - 1\right) R + C. \tag{24}$$

In the equilibrium condition, the above inequation takes equality. The credit creation capacity of the bank under the LCR regulation, denoted as $L_{\max}^{LCR}$, can be thus obtained as follows:

$$L_{\max}^{LCR} = \left(\frac{4}{\mu r_{LCR}} - 1\right) R + C. \tag{25}$$

Likewise, the corresponding expressions for $L_{\max}^{LCR}$ under the condition of $IF^* < 0.75OF^*$[5] can be given by

$$L_{\max}^{LCR} = \frac{(1+\theta)\left[R(1-\mu r_{LCR}) + \mu r_{LCR} C\right]}{r_{LCR}\left[\mu(1+\theta) - 1\right]}. \tag{26}$$

By combing Equations (25) and (26), the full expression for $L_{\max}^{LCR}$ can be stated as follows:

$$L_{\max}^{LCR} = \begin{cases} \left(\dfrac{4}{\mu r_{LCR}} - 1\right) R + C, & IF^* \geq 0.75OF^*; \\ \dfrac{(1+\theta)\left[R(1-\mu r_{LCR}) + \mu r_{LCR} C\right]}{r_{LCR}\left[\mu(1+\theta) - 1\right]}, & IF^* < 0.75OF^*. \end{cases} \tag{27}$$

With a few additional manipulations, as shown in Appendix B, we can replace the conditions of $IF^* \geq 0.75OF^*$ and $IF^* < 0.75OF^*$ with their alternative expressions and obtain the final expression for $L_{\max}^{LCR}$, i.e.,

$$L_{\max}^{LCR} = \begin{cases} \left(\dfrac{4}{\mu r_{LCR}} - 1\right) R + C, & \dfrac{C}{R} \geq 1 + \dfrac{3(1+\theta)\mu - 4}{\mu r_{LCR}}; \\ \dfrac{(1+\theta)\left[R(1-\mu r_{LCR}) + \mu r_{LCR} C\right]}{r_{LCR}\left[\mu(1+\theta) - 1\right]}, & \dfrac{C}{R} < 1 + \dfrac{3(1+\theta)\mu - 4}{\mu r_{LCR}}. \end{cases} \tag{28}$$

Similarly, we can derive the expression for the credit creation capacity under the CAR regulation. By injecting Equation (22) back to Inequation 21 and rearranging the inequation, we have

$$L(t) \leq \frac{C}{\gamma r_{CAR}}. \tag{29}$$

Considering the equilibrium state condition in Equation (10) and forcing the above inequation to take equality, we infer that

$$L_{\max}^{CAR} = \frac{C}{\gamma r_{CAR}}, \tag{30}$$

[5] Note that we do not consider the uncommon condition where $\mu < \frac{1}{1+\theta}$. See Appendix A for more details.

Table 3
Comparison of the standalone impacts of different Basel III regulations on bank credit creation.

	LCR regulation	CAR regulation	LR regulation
Purpose	Guard against liquidity risk from maturity mismatch	Guard against solvency risk from loan default	Encourage deleverage and limit balance sheet expansion
Requirement	$HQLA \geq r_{LCR}{}^{*}NCOF$	$C \geq r_{CAR}{}^{*}RWA$	$C \geq r_{LR}{}^{*}TA$
Safety buffers	High quality liquid assets	Capital	Capital
Equilibrium credit creation capacity	$L_{\max}^{LCR} = \begin{cases} (\frac{4}{\mu r_{LCR}} - 1)R + C, \ IF^{*} \geq 0.75OF^{*}; \\ \frac{(1+\theta)\left[R(1-\mu r_{LCR}) + \mu r_{LCR}C\right]}{r_{LCR}\left[\mu(1+\theta)-1\right]}, \ IF^{*} < 0.75OF^{*}. \end{cases}$	$L_{\max}^{CAR} = \frac{C}{\gamma r_{CAR}}$	$L_{\max}^{LR} = \frac{C}{r_{LR}} - R$
Equilibrium bank lending	$LF_{LCR} = \begin{cases} \frac{8-2\mu r_{LCR}}{\mu(1+\theta)r_{LCR}}R + \frac{2}{1+\theta}C, \ IF^{*} \geq 0.75OF^{*}; \\ \frac{2\left[R(1-\mu r_{LCR}) + \mu r_{LCR}C\right]}{r_{LCR}\left[\mu(1+\theta)-1\right]}, \ IF^{*} < 0.75OF^{*}. \end{cases}$	$LF_{CAR} = \frac{2C}{\gamma(1+\theta)r_{CAR}}$	$LF_{LR} = \frac{2C}{(1+\theta)r_{LR}} - \frac{2}{1+\theta}R$
Dependence of bank lending on the corresponding safety buffer	$\frac{\partial LF_{LCR}}{\partial R} > 0$	$\frac{\partial LF_{CAR}}{\partial C} > 0$	$\frac{\partial LF_{LR}}{\partial C} > 0$
Dependence of bank lending on the minimum policy ratio	$\frac{\partial LF_{LCR}}{\partial r_{LCR}} < 0$	$\frac{\partial LF_{CAR}}{\partial r_{CAR}} < 0$	$\frac{\partial LF_{LR}}{\partial r_{LR}} < 0$
Dependence of bank lending on other parameters	$\frac{\partial LF_{LCR}}{\partial \mu} < 0$, $\frac{\partial LF_{LCR}}{\partial \theta} < 0$	$\frac{\partial LF_{CAR}}{\partial \gamma} < 0$, $\frac{\partial LF_{CAR}}{\partial \theta} < 0$	$\frac{\partial LF_{LR}}{\partial \theta} < 0$

where $L_{\max}^{CAR}$ denotes the credit creation capacity of the bank under the CAR regulation.

Likewise, we can prove that the LR regulation also puts an upper bound on the total level of loans, as indicated by the following inequation:

$$L(t) \leq \frac{C}{r_{LR}} - R. \tag{31}$$

Therefore, the expression for the credit creation capacity under the LR regulation, $L_{\max}^{LR}$, can be obtained as

$$L_{\max}^{LR} = \frac{C}{r_{LR}} - R. \tag{32}$$

Furthermore, according to the relationship between the loan stock and the new lending flow in the equilibrium state, shown in Equation (13), the equilibrium expressions for the new lending flow under each regulation can be stated as:

$$LF_{LCR} = \begin{cases} \frac{8-2\mu r_{LCR}}{\mu(1+\theta)r_{LCR}}R + \frac{2}{1+\theta}C, \ IF^{*} \geq 0.75OF^{*}; \\ \frac{2\left[R(1-\mu r_{LCR}) + \mu r_{LCR}C\right]}{r_{LCR}\left[\mu(1+\theta)-1\right]}, \ IF^{*} < 0.75OF^{*}, \end{cases} \tag{33}$$

$$LF_{CAR} = \frac{2C}{\gamma(1+\theta)r_{CAR}}, \tag{34}$$

$$LF_{LR} = \frac{2C}{(1+\theta)r_{LR}} - \frac{2}{1+\theta}R. \tag{35}$$

We have obtained the equilibrium expressions for the loan stock and the new lending flow, which allows us to explore their dependence on corresponding behavioral and policy parameters. The following section focuses on the new lending flow, which has a closer and more direct link with aggregate demand.

4.1.2. Determinants of bank lending under each individual regulation

In general, the determinants of bank lending can be categorized into three groups: the level of relevant safety buffer, the minimum policy ratio, and the parameters reflecting the risk condition related to the bank's balance sheet structure and the underlying economic environment. First, regardless of the regulation in effect, bank lending always increases with the expansion of the corresponding safety buffer ($\frac{\partial LF_{\max}^{LCR}}{\partial HQLA} > 0$, $\frac{\partial LF_{\max}^{CAR}}{\partial C} > 0$ and $\frac{\partial LF_{\max}^{LR}}{\partial C} > 0$), and decreases with a rising minimum policy ratio ($\frac{\partial LF_{\max}^{LCR}}{\partial r_{LCR}} < 0$, $\frac{\partial LF_{\max}^{CAR}}{\partial r_{CAR}} < 0$ and $\frac{\partial LF_{\max}^{LR}}{\partial r_{LR}} < 0$).

Moreover, the dependence of bank lending on parameters reflecting underlying risk conditions varies for different prudential regulations. Under the LCR regulation, bank lending increases when the bank has access to a more stable debt-based financing source ($\frac{\partial LF_{\max}^{LCR}}{\partial \mu} < 0$). Under the CAR regulation, a bank can lend more if its loans bear lower default risk ($\frac{\partial LF_{\max}^{LCR}}{\partial \gamma} < 0$). For all three regulations, bank lending increases when the average maturity of loans is shorter ($\frac{\partial LF_{\max}^{LCR}}{\partial \theta} < 0$).

In Table 3, we summarize the standalone effects of Basel III prudential regulations on bank credit creation.

4.1.3. The transmission of BLC under each individual regulation

Having demonstrated the standalone impacts of each prudential regulation on the equilibrium state of credit creation, we now examine the response of bank lending to quantitative monetary shocks when only one regulation is in effect. Quantitative monetary shocks are portrayed as changes in the level of reserves. We denote the sensitivity of bank lending to changes in reserves under the LCR, CAR, and LR regulations respectively as S_{LCR}, S_{CAR} and S_{LR}. By taking the partial derivative of the equilibrium new lending flow given in Equations (33)–(35) with respect to reserves, we obtain the corresponding expressions for S_{LCR}, S_{CAR} and S_{LR}.

When the LCR regulation alone is imposed, we have

$$S_{LCR} = \frac{\partial LF_{LCR}}{\partial R} = \begin{cases} \frac{8-2\mu r_{LCR}}{\mu(1+\theta)r_{LCR}}, \ IF^{*} \geq 0.75OF^{*}; \\ \frac{2(1-\mu r_{LCR})}{r_{LCR}\left[\mu(1+\theta)-1\right]}, \ IF^{*} < 0.75OF^{*}. \end{cases} \tag{36}$$

It can be proved that

$$S_{LCR} > 0. \tag{37}$$

This indicates that the conventional BLC exists whereby bank lending increases due to a reserve expansion. Compared with the traditional BLC under the reserve requirement, the response of bank lending to reserve shocks is determined not only by the required policy ratio but also on bank-specific characteristics. In other words, the strength of the BLC under the LCR regulation is a decreasing function of the average maturity of loans ($\frac{\partial LF_{LCR}}{\partial \theta} < 0$), the stability of its debt-based financing ($\frac{\partial LF_{LCR}}{\partial \mu} < 0$), and the minimum regulatory requirement ($\frac{\partial LF_{LCR}}{\partial r_{LCR}} < 0$).

When the bank is constrained only by the CAR regulation, changes in the reserve quantity have no impact on bank lending, i.e.,

$$S_{CAR} = \frac{\partial LF_{CAR}}{\partial R} = 0. \tag{38}$$

In other words, the BLC is non-operative due to the imposition of the CAR regulation because the credit creation capacity is constrained by the sufficiency of bank capital, which cannot be directly affected by the changes in reserves.

Furthermore, the response of bank lending to a reserve shock under the LR regulation alone is given by

$$S_{LR} = \frac{\partial LF_{LR}}{\partial R} = -\frac{2}{1+\theta} < 0. \tag{39}$$

This implies that when banks are leverage-constrained, the expansion of reserves may reduce the supply of bank credit rather than boost it. When it is difficult for the bank to increase capital, the LR regulation sets a maximum limit on the total amount of bank assets. Consequently, the increase of reserves must be offset by a corresponding decrease in other assets, which thus imparts a crowding effect on the bank loans in our case. This effect can be mitigated when banks reduce their security holdings instead of downsizing bank loans.[6] Nevertheless, to the extent that the reserve expansion is not entirely offset, a reverse BLC may arise where an expansionary reserve shock induces a contractive effect on the bank's creation capacity, thus reducing bank lending.

It is worthwhile to compare our conclusions with Martin et al. (2016), who also indicates that reserve shocks could have no or negative impact on bank lending. Our research differs from their work as our conclusions are derived explicitly from the imposition of the CAR and LR regulations, while their analysis is based on the assumption of a cost associated with banks' balance sheet size. As Martin et al. (2016) argues, the level of bank lending is independent of bank reserves when the costs for expanding the balance sheet are moderate, while bank lending becomes a decreasing function of reserves when the supply of reserves and balance sheet costs are sufficiently large. Although our model's response of bank lending to reserve shocks is determined by which prudential regulation serves as the binding constraint, it is not difficult to make a reconciliation. With the respective goals of the LR and CAR regulations being overall size control and asset risk enhancement, banks constrained by the LR regulation are more likely to face a higher cost associated with the expansion of their balance sheet[7] than banks constrained by the CAR regulation. Diamond, Jiang, and Ma (2020) bears a similar perspective and argues that forcing the banking sector to hold the large number of reserves created by QE reduces QE's ability to stimulate the economy. While Diamond et al. (2020) focuses on the effectiveness of a monetary policy, they also point out the fact that the relaxation of prudential regulations could potentially alleviate the unintended consequence of QE.

4.2. Collective impact of the simultaneous imposition of multiple regulations

Having demonstrated the different impacts of the LCR, CAR, and LR regulations on the credit creation process and the BLC of monetary transmission, we now examine the collective consequence of the simultaneous imposition of all three regulations. Section 4.B.1 shows that when all three regulations take effect simultaneously, the credit creation capacity is constrained by the most stringent prudential regulation. In addition, we examine in detail how the effective binding regulatory constraint varies across different risk conditions determined by the general economic environment and the bank's risk management strategy. Furthermore, Section 4.B.2 explores the variations of the BLC under the influence of the multi-polar regulatory framework.

4.2.1. The transition of the effective binding constraint across different risk conditions

When multiple regulations take effect simultaneously, the bank's credit creation capacity, denoted as $L^{all}_{\max}$, is determined by the most stringent constraint, i.e.,

$$L^{all}_{\max} = min\{L^{LCR}_{\max}, L^{CAR}_{\max}, L^{LR}_{\max}\}. \tag{40}$$

In other words, an effective binding regulation is that gives the smallest credit creation capacity among all imposed regulations. To determine which regulation is the binding constraint, we compare the expressions for the credit creation capacity when each regulation is imposed alone, given by Equations (28), (30) and (32). When two expressions take identity, we can derive the boundary condition that marks the transition of the two corresponding regulations as the effective binding constraint on credit creation. Specifically, the boundary condition between the LCR and CAR regulations is given by

$$\frac{C}{R} = \begin{cases} \dfrac{(4-\mu r_{LCR})\gamma r_{CAR}}{\mu r_{LCR}(1-\gamma r_{CAR})}, & IF^* \geq 0.75OF^*; \\ \dfrac{\gamma(1+\theta)(1-\mu r_{LCR})r_{CAR}}{\left[\mu(1+\theta)(1-\gamma r_{CAR})-1\right] r_{LCR}}, & IF^* < 0.75OF^*. \end{cases} \tag{41}$$

The boundary condition between the LCR and LR regulations is

$$\frac{C}{R} = \begin{cases} \dfrac{4r_{LR}}{\mu r_{LCR}(1-r_{LR})}, & IF^* \geq 0.75OF^*; \\ \dfrac{(1+\theta-r_{LCR})r_{LR}}{\left[\mu(1+\theta)(1-r_{LR})-1\right] r_{LCR}}, & IF^* < 0.75OF^*. \end{cases} \tag{42}$$

The boundary condition between the CAR and LR regulations is

$$\frac{C}{R} = \frac{\gamma r_{CAR} r_{LR}}{\gamma r_{CAR} - r_{LR}}. \tag{43}$$

In addition, as shown in Appendix B, the condition of $IF^* \geq 0.75OF^*$ for the LCR regulation is equivalent to

$$\begin{aligned} &\frac{C}{R} \geq 1 + \frac{3(1+\theta)\mu - 4}{\mu r_{LCR}} \text{ and } (1+\theta)\mu \leq \frac{4}{3}, \\ &\text{or } \frac{C}{R} \leq 1 + \frac{3(1+\theta)\mu - 4}{\mu r_{LCR}} \text{ and } (1+\theta)\mu > \frac{4}{3}. \end{aligned} \tag{44}$$

Similarly, the alternative expression for the condition of $IF^* < 0.75OF^*$ is

$$\begin{aligned} &\frac{C}{R} < 1 + \frac{3(1+\theta)\mu - 4}{\mu r_{LCR}} \text{ and } 1 < (1+\theta)\mu \leq \frac{4}{3}, \\ &\text{or } \frac{C}{R} > 1 + \frac{3(1+\theta)\mu - 4}{\mu r_{LCR}} \text{ and } (1+\theta)\mu \geq \frac{4}{3}, \\ &\text{or } (1+\theta)\mu \leq 1. \end{aligned} \tag{45}$$

From Equations (41)–(45), we can identify the determinants for which regulation is the effective binding constraint on bank lending: the capital-to-reserve ratio ($\frac{C}{R}$); the stability of the debt-based financing source (μ); the average maturity (θ) and default risk (γ) of loans; and the minimum requirements of the LCR, CAR, and LR regulations (r_{LCR}, r_{CAR}, r_{LR}).

In other words, when multiple regulations are imposed simultaneously, the effective binding regulation depends on the general risk condition faced by the bank and the relative stringency of the imposed regulations.

Since the minimum policy requirements are not expected to experience large variations under a relatively stable regulatory regime, we set $r_{LCR} = 100\%, r_{CAR} = 7\%, r_{LR} = 3\%$ as the general standards provided in the Basel-III accord (BCBS, 2010, 2013a,b).

Other parameters, i.e., $\mu, \theta, \gamma, \frac{C}{R}$, are varied to reflect changes in the bank balance sheet and the underlying economic condition. To find an anchor for parameter variation, we calculate the average, the maximum, and the minimum values for concerned parameters using the historical data for domestically chartered US commercial banks between January 2000 and December 2021. The results are shown in Appendix C along with the explanation for the selected calibration strategy and data source. The effective binding regulations for different parameter combinations are shown in Fig. 3. The default risk γ is shown on the vertical axis in each subplot, while the capital-to-reserve ratio $\frac{C}{R}$ is displayed on the horizontal axis. These two parameters form a two-dimensional

[6] In reaction to the pressure of asset downsizing induced by reserve shocks, banks can choose among different types of assets. This choice depends on the relative risk and returns associated with these assets and their original shares.

[7] Such relation is modeled in more details by Martin et al. (2013).

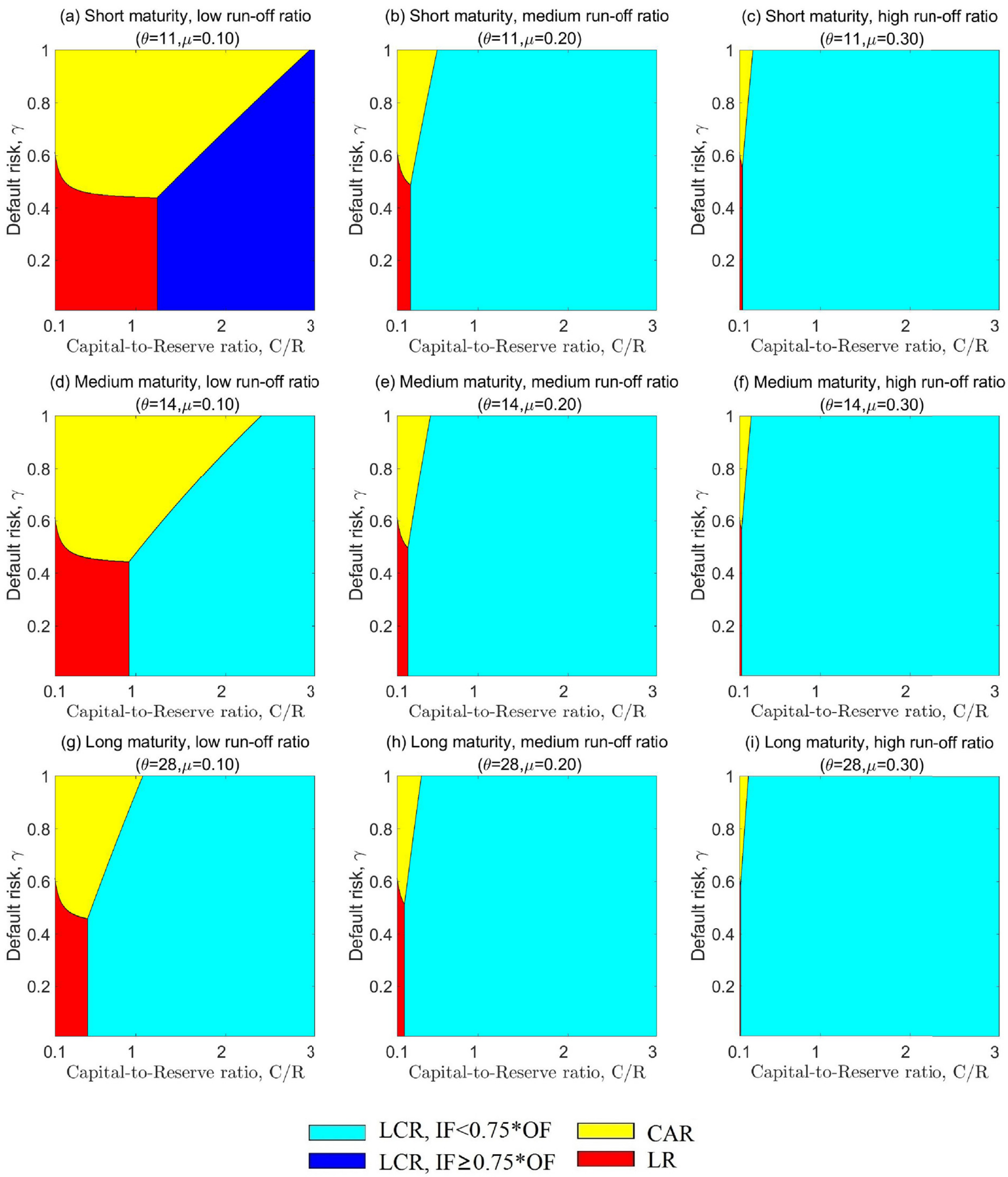

Fig. 3. The transitions of effective binding regulation across different conditions. The effective binding regulation on bank lending is indicated by different colors, as shown in the legend. Boundary conditions in Equations (41)–(45) are indicated by black lines. The default risk γ and the capital-to-reserve ratio $\frac{C}{R}$ are shown respectively in the horizontal and vertical axes. The values of average loan maturity θ and the run-off ratio of debt-based financing source μ vary in (a–i). **Implications:** The solvency risk is higher with larger γ and $\frac{C}{R}$, while the liquidity risk is higher with larger θ and μ. When the risk condition change, the effective binding regulation constraining banks also varies. Capital-based regulations dominate when the solvency risk is relatively larger than the liquidity risk. Otherwise, the liquidity regulation becomes the binding constraint. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

state space for each regulation to act as the effective binding constraint on bank credit creation. Different colors indicate the LCR, CAR, and LR regulations. Liquidity risk is reflected by the average maturity θ and the stability of debt-based funding μ, whose values vary across different subplots.

The first conclusion from Fig. 3 is that different regulations become effective binding constraints in different risk conditions. In general, the LCR regulation takes effect when the bank holds a relatively high-capital position; its effective domain enlarges with the increase of the liquidity risk, as embodied by longer maturity (θ) and lower funding stability (μ). Conversely, the capital-based regulations dominate in conditions with higher exposure to the solvency risk as the bank takes a lower relative capital-to-reserve position ($\frac{C}{R}$). Moreover, the CAR regulation is responsible for conditions with higher default risk (γ), while the LR regulation becomes the dominating constraint in conditions with lower default risk (γ).

4.2.2. The variation of the bank lending channel under the simultaneous imposition of multiple regulations

The transmission mechanism of monetary shocks via the BLC is governed by the dominating prudential regulation, which varies across different risk conditions. Therefore, it is not surprising to find greater complexity in the operation of the BLC when multiple prudential regulations are simultaneously taking effect.

To better illustrate this point, Fig. 4 presents an example of how reserve shocks of varying sizes and stances (expansionary or contractionary) propagate through banks with different levels of capital. Banks with different capital levels respond heterogeneously to the same reserve shock. The main reason for such heterogeneity is that the effective binding constraint on banks with different capital levels are not the same. For instance, when the level of capital is low, the LR regulation determines the bank's credit creation capacity. Under this condition, a reversed BLC emerges, where the relationship between the change in bank lending and reserves is negative, as exemplified in Fig. 4 (a). In contrast, when the bank maintains a higher capital position, the BLC works in the traditional way that bank lending increases with the expansion of reserves, as shown in Fig. 4 (c). At the intermediate capital level, the transmission of reserve shocks via the BLC could become neither linear nor monotonic. As shown in Fig. 4 (b), when the monetary shock yields excessive reserves, the LR regulation takes binding effect, so that bank lending decreases as the level of reserves increases. In contrast, when the level of reserves is not excessive, the LCR regulation becomes the dominant constraint, so that bank lending increases with reserve expansion. In other words, if a reserve shock changes the effective binding constraint on the bank's credit creation capacity, the response of bank lending to this shock also changes.

Note that the definition of high or low-capital position is comparative. Apart from the bank's capital and reserve position, the effects of reserve shocks on bank lending also depend on other risk parameters, such as the average maturity of loans θ, the default risk of loans γ, and the run-off ratio of deposits μ. The BLC's performances under several representative risk conditions are demonstrated in Fig. 5. Although the bank's capital position is the same as that in Fig. 4, the transmission process of monetary shocks via the BLC changes dramatically as the risk condition varies. Specifically, the severity of liquidity risk increases with larger θ and μ, while the solvency risk intensifies with larger γ. Fig. 5 (a) indicates a condition with high liquidity risk and high default risk, while Fig. 5 (f) shows a condition with low liquidity risk and low default risk. (b–e) Presents conditions that fall between. Fig. 4(a–c) shows a position relation between bank lending and reserve expansion as indicated by the traditional BLC. However, when the liquidity risk falls as the values for average maturity θ increases or the run-off ratio decreases, the transmission of monetary shocks via the BLC become a non-monotonic and nonlinear process.

Therefore, policymakers need to identify which regulation is the effective binding constraint for individual banks in the empirical evaluation of the BLC's efficacy, especially in countries and periods where multiple Basel-III regulations are simultaneously implemented. More specifically, in empirical analysis, when relating the cross-sectional characteristics of banks to the extent they can effectively pass on monetary shocks, it would not be enough to classify the banks only by the risk-based capital adequacy ratio or other single regulatory ratios.

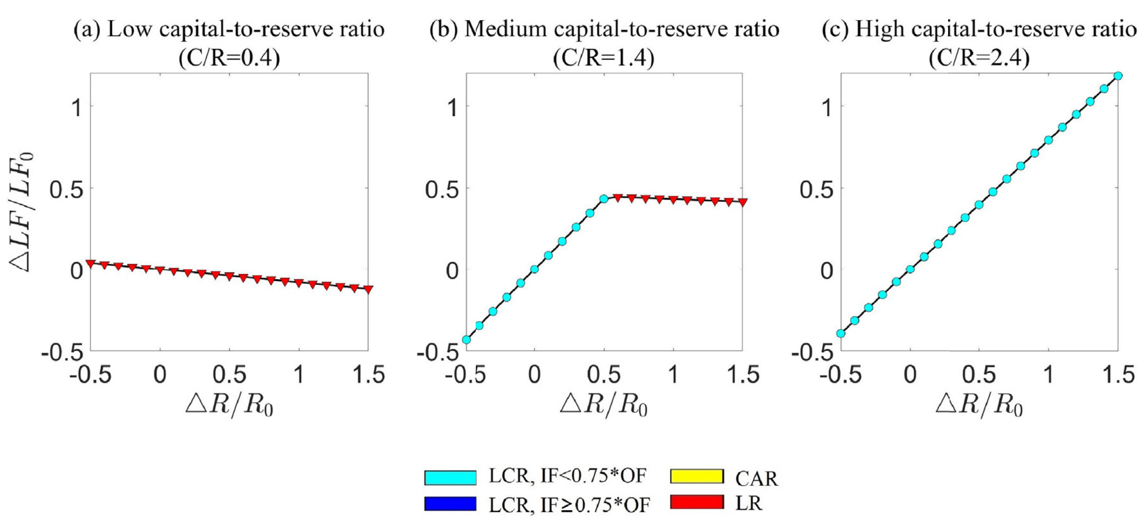

Fig. 4. Heterogeneous responses of bank lending to the same reserve shocks for banks with different capital-to-reserve position when the LCR, CAR and LR regulations are simultaneously imposed. In (a–c), the capital-to-reserve ratio is varied from low to high. The initial level of reserves and other parameters are kept the same with $R_0 = 1000, \theta = 14, \mu = 0.1, \gamma = 0.04$. The size of the shock relative to the initial level of reserves, $\frac{\triangle R}{R_0}$, is shown on the horizontal axis with positive (negative) values indicating the expansion (contraction) of reserves. The change in bank lending relative to its initial value, $\frac{\triangle LF}{LF_0}$, is displayed on the vertical axis. The effective binding regulation is indicated by different symbols and colors as shown in the legend. **Implications:** Due to the transition of the effective binding constraints, banks with different capital levels respond heterogeneously to the same reserve shock. The conventional operation of the BLC, where bank lending increases (decreases) with expansionary (contractionary) reserve shock, appears only when the bank has sufficient capital holdings, as shown in (c). In other cases, an expansionary monetary shock can have adverse effects (a) or nonlinear and non-monotonic effects (b) on bank lending. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

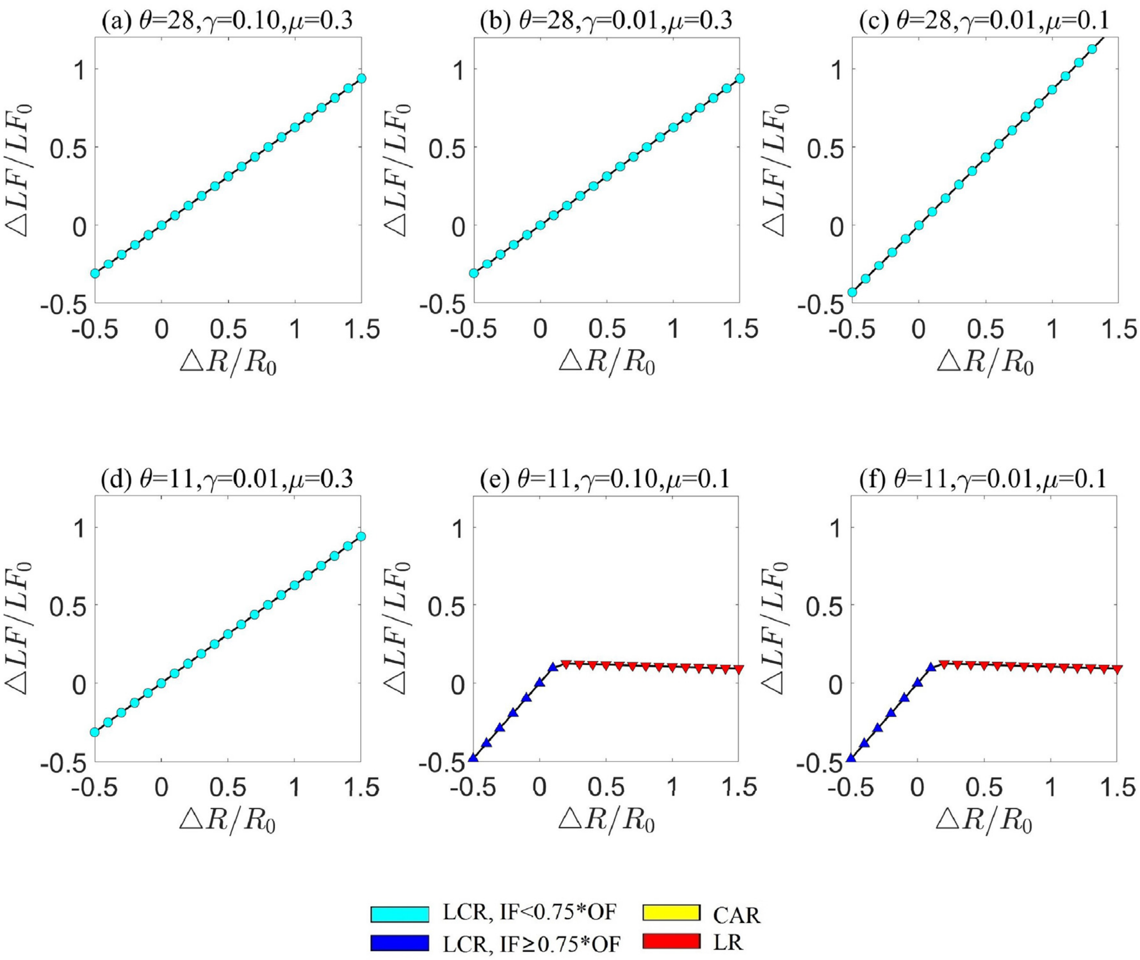

Fig. 5. Variation in the response of new bank lending to reserve shocks under different conditions. In (a–f), the initial level of reserves and that of capital are kept the same with $C/R = 1.4$. In contrast, the average maturity of loans θ, the average risk of loan default γ, and the run-off ratio of deposits μ are varied to reflect different risk conditions. The severity of liquidity risk increases with larger θ and μ while the insolvency risk intensifies with larger γ. Specifically, (a) presents a condition for high liquidity and default risk, while (f) presents a condition for low liquidity and default risk. (b–e) Presents cases that fall between. The indications for the axes, symbols, and colors are the same as Fig. 4. **Implications:** Apart from the bank's capital and reserve position, the effects of reserve shocks on bank lending also depend on other risk parameters, such as the average maturity of loans θ, the default risk of loans γ, and the run-off ratio of deposits μ. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Instead, we should consider multiple regulatory metrics to account for the combined policy effects. This would require a better resolution of the bank-level data and a more detailed and targeted classification of banks regarding their liquidity and capital positions.

5. Concluding remarks

This paper examines the standalone and cumulative effects of multiple Basel-III regulations on the transmission of quantitative monetary shocks via the bank lending channel (BLC). In our analysis, banks' lending capacity is not constrained by their access to reservable deposits under a binding reserve requirement but by the number of safety buffers in the system and the stringency of different prudential regulations proposed in the Basel-III accord. The process of credit and money creation naturally increases the bank's exposures to liquidity and solvency risks associated with loan defaults and maturity mismatch. These risks are managed by maintaining adequate capital and high-quality liquidity assets as safety buffers. The limited amount of safety buffers and the imposition of prudential regulations constrain the bank's credit creation capacity, leading to a reformulated BLC. To account for the transition of the prudential regulation framework toward a multi-polar regime, we consider three different regulations in the Basel-III accord, i.e., the risk-based capital adequacy ratio (CAR) regulation, liquidity coverage ratio (LCR) regulation, and the leverage ratio (LR) regulation.

Although we use a rather parsimonious model, the stock-flow consistent framework and bank-centered perspective allow us to explore some of the most fundamental properties of the new Basel prudential framework. In particular, we demonstrate how the operation of the BLC varies when the bank is subject to different prudential regulations. When the LCR regulation alone takes effect, a normal BLC exists where the bank lending increases with the expansion of reserves. As the result of the more sophisticated design of the LCR regulation, the effectiveness of the BLC is affected both by the minimum regulatory ratio as the required reserve ratio in the traditional BLC, and by bank-specific characteristics, including capital level, loan maturity, and funding stability. Nevertheless, under the CAR regulation, changes in the number of reserves may have no impact on bank lending, especially when the bank does not have enough capital holdings to cover the additional risk exposure associated with the potential default of the new loan. In the case of binding LR regulation, the increase in reserves, rather than boosting bank lending, may reduce the bank's credit supply. In other words, a reserved BLC could result from the crowding-out effect of reserves on bank loans. Shocking as this assertion may seem, there have been vigorous debates concerning the potential adverse effect of the LR regulation on market liquidity in the Federal Reserve System's board meetings. In 2014, the Board decided to impose a supplementary LR of 2% on globally systemically important banks in addition to the internationally agreed-upon 3% minimum LR requirement. Although there is a general cognition that bank regulation has reduced liquidity in financial markets, some policymakers believe that "a small reduction in liquidity from regulatory changes 'even if present, which is not obvious' may be a reasonable price to pay for greater safety".

Moreover, by considering the collective consequences when all three regulations are simultaneously imposed, our work adds to the nascent literature related to the multi-polar prudential regulation framework. First, by identifying which regulation most stringently constrains bank credit creation, we find that each regulation's binding condition is highly dependent on bank-specific characteristics and the corresponding economic state. Specifically, the LCR regulation is most likely to influence banks with a relatively high capital position, long loan maturity, and unstable debt-based financing. Conversely, capital-based requirements assume importance mainly when the capital holdings of the banking system are insufficient compared to its liquidity buffer. The risk-based and non-risk-based capital regulations complement each other by taking effects in high and low default risk situations. Second, due to the transitions of the effective binding constraint across different banks and with varying economic conditions, the reformulated BLC, based on Basel–III–type prudential regulations, is much more complicated than the traditional BLC, based on the reserve requirement. The effect of reserves shocks on bank lending varies across banks with different capital and depends on the stance and size of the shock itself. Additionally, the relation between reserve shocks and changes in bank lending is also closely related to the bank's risk condition, which varies due to changes in the structure of its balance sheet or the underlying economic environment.

Several policy implications can be drawn from our results. First, while the multi-polar regulatory framework is designed for better protection against various risks, policymakers should also be aware of its side effect of interfering with the monetary transmission channel. Specifically, it adds to the heterogeneity in banks' responses to the same monetary shock and the sensitivity of bank lending to the underlying economic condition. In the worst-case scenario, the multi-polar regulatory framework may add to systemic risk. Second, under multiple prudential regulations, the reformulated bank lending channel demonstrates nonlinearity, non-monotonicity, and path-dependency characteristics. This new regulatory condition puts forward more significant challenges for policymakers in choosing the appropriate strength of policy shocks and regulatory requirements than the traditional regulatory condition, where the reserve requirement or single prudential regulation takes effect. Third, to unclog the monetary transmission channel, it is essential to alleviate the binding constraint faced by individual banks. One of the greatest challenges in the conduct of monetary policy is the frustration of "pushing on the string". Such frustration is aggravated especially in economic downturns by the compound effects of enhancing bank supervision, the deterioration of bank balance sheets, and market-driven decreases in risk preference. Therefore, we find the deferral of Basel-III implementation after the outbreak of Covid-19 in many countries a suitable example of the coordination between prudential regulations and monetary policy in times of stress. Such coordination enhances the operational capacity of banks and supervisors to adverse shocks and helps protect the effectiveness of unconventional monetary policies. Lastly, we argue that identifying the effective binding constraint is a good exercise for policymakers to decide the necessity of employing more targeted monetary instruments, like the Capital Purchase Program. Particularly, if a bank suffers from a capital shortage, it is more effective if the central bank can directly inject capital into the bank than expanding reserves.

The current study is a preliminary attempt to probe the complexity of the interconnection of modern banking practices. While we expect our conclusions to hold with more sophisticated assumptions, several open questions are left for future research to address. Theoretically, a deeper and more comprehensive understanding of the impacts of monetary shocks on bank lending may be obtained by relaxing the assumptions of exogenous capital and fixed risk preference, which incorporate additional transmission channels other than the BLC, including the bank capital channel and the risk-taking channel. Furthermore, the combined effect of monetary policy and prudential regulations on the price of lending is another important issue not discussed in this paper.[8] In addition, although we emphasized on the dependence of the BLC on bank-specific characteristics, we have not explicitly modeled the heterogeneity and interconnections among banks, which could be a fruitful direction for future studies. Moreover, our analysis raises interesting empirical questions regarding which prudential regulation dominates individual banks' actual practice and through which bank monetary policies with different stances take effects.

Declaration of competing interest

We would like to submit an original research article entitled "A reformulation of the bank lending channel under multiple prudential regulations" for consideration by Economic Modelling. We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Acknowledgements

This study is supported by the National Social Science Foundation of China (grants no. 20CGL007) and the National Natural Science Foundation of China (grants no. 61773069 & no.71731002). The authors thank the reviewers and editors for their valuable input.

Appendix A. Details for deriving Eq. (26)

Consider the equilibrium state and the balance sheet consistency. Based on the corresponding relations for RP^*, D^* and L^* in Equations (11)–(13), the Inequation 20 under the condition of $IF^* < 0.75^* OF^*$ can be restated as

$$r_{LCR} \leq \frac{R}{\mu(R + L_{LCR} - C) - 0.5\left(\frac{2}{1+\theta}\right)L_{LCR}} = \frac{R}{\mu(R - C) + \left(\mu - \frac{1}{1+\theta}\right)L_{LCR}}, \tag{A1}$$

[8] Empirical evidence (Altavilla et al., 2020) suggests the pass-through of monetary policy via the interest rates with different terms and risk structure is another critical aspect in evaluating the policy effect on the lending condition apart from the traditional focus of the quantity of total lending.

where L_{LCR} denotes the corresponding equilibrium loan stock under the LCR regulation.

Because the total net cash outflow should always be positive, we have $\mu(R-C)+(\mu-\frac{1}{1+\theta})L_{LCR}>0$. Thus the above inequation can be rearranged as

$$r_{LCR}\left(\mu-\frac{1}{1+\theta}\right)L_{LCR}\leq(1-\mu r_{LCR})R+\mu r_{LCR}C, \tag{A2}$$

which is equivalent to

$$\begin{cases} L_{LCR}\leq\dfrac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}, & if\ \mu>\dfrac{1}{1+\theta}; \\ L_{LCR}\geq\dfrac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}, & if\ \mu<\dfrac{1}{1+\theta}; \\ (1-\mu r_{LCR})R+\mu r_{LCR}C\geq 0, & if\ \mu=\dfrac{1}{1+\theta}. \end{cases} \tag{A3}$$

Because $(1-\mu r_{LCR})R+\mu r_{LCR}C\geq 0$ should always hold,[9] we can infer that $\frac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}\leq 0$ if $\mu<\frac{1}{1+\theta}$. Therefore, the above inequation can be simplified and rewritten as

$$\begin{cases} L_{LCR}\leq\dfrac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}, & if\ \mu>\dfrac{1}{1+\theta}; \\ L_{LCR}\geq 0, & if\ \mu\leq\dfrac{1}{1+\theta}. \end{cases} \tag{A4}$$

In other words, when $\mu<\frac{1}{1+\theta}$, i.e. the bank enjoys high funding stability in terms of the maturity of its uses of funds, the LCR regulation puts no constraint on the credit creation capacity of the bank. Nonetheless, we find such condition less common in the reality. Specifically, it is unlikely for the average maturity of the commercial bank to be less than 12 months, i.e. $\theta\leq 12$, which means that the run-off ratio of the bank's non-equity funding should be less than 7.7% so as to satisfy $\mu<\frac{1}{1+\theta}$. According to the Basel III accord, the category of funding receiving a run-off factor less than 10% usually requires the funding to be covered by the deposit insurance scheme (3–5%), or to have residual maturity greater than 30 days (0%). On the other hand, higher run-off factors, ranging from 10% to 100% are assigned for debts such as wholesale funding, or funding without or with weak asset backup. Considering the fact that wholesale funding could constitute 40–50% of the total non-equity funding of the bank in the United States, we find it acceptable to apply the additional assumption of $\mu>\frac{1}{1+\theta}$. Consequently, the constraint of the LCR regulation on the equilibrium loan stock under the condition of $IF<0.75^{*}OF$ can be eventually stated as

$$L_{LCR}\leq\frac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}, \tag{A5}$$

where $\mu>\frac{1}{1+\theta}$. Forcing the above inequation to take equality, we obtain the expression in Equation (26) for the credit creation capacity of the bank under the LCR regulation when $IF<0.75^{*}OF$, i.e.

$$L_{\max}^{LCR}=\frac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]},$$

where $\mu>\frac{1}{1+\theta}$.

Appendix B. Alternative expressions for the conditions of $IF*\geq 0.75OF*$ and $IF*<0.75OF*$

Based on Equations (11)–(13) and (17) and (18), the condition of $IF^{*}\geq 0.75OF^{*}$ can be restated as

$$\left[1-0.75(1+\theta)\mu\right]L_{\max}^{LCR}\geq 0.75(1+\theta)\mu(R-C). \tag{B1}$$

Substituting $L_{\max}^{LCR}$ with its corresponding expression in Equation (25), we can rewrite the condition of $IF^{*}\geq 0.75OF^{*}$ as

$$\left[1-0.75(1+\theta)\mu\right]*\left[\left(\frac{4}{\mu r_{LCR}}-1\right)R+C\right]\geq 0.75(1+\theta)\mu(R-C), \tag{B2}$$

which is equivalent to

$$\frac{C}{R}\geq 1+\frac{3(1+\theta)\mu-4}{\mu r_{LCR}}. \tag{B3}$$

$$\left[1-0.75(1+\theta)\mu\right]*\frac{(1+\theta)\left[(1-\mu r_{LCR})R+\mu r_{LCR}C\right]}{r_{LCR}[\mu(1+\theta)-1]}<0.75(1+\theta)\mu(R-C). \tag{B4}$$

With a few manipulations, the above inequation can be restated as follows:

$$\frac{C}{R}<1+\frac{3(1+\theta)\mu-4}{\mu r_{LCR}}. \tag{B5}$$

Similarly, the alternative expression for the condition of $IF^{*}<0.75OF^{*}$ is

[9] In normal conditions, $r_{LCR}\leq 1$.

Appendix C. Parameter Calibration

The following table provides the historical values for the concerned parameters in our model, which are used as a baseline for parameter variation in the analyses of Section 4.B. The last three columns present the mean, maximum and minimum values for the historical data for all domestically chartered commercial banks in the United States between January 2000 and December 2021. More specifically, the value for bank capital (C) is calculated as the difference between total assets and total liabilities. The value for reserves (R) is calculated as the sum of cash assets, fed funds and reverse RPs. The value for the average loan maturity (θ) is calibrated based on the weighted average maturity for all C&L loans. The value for the average loan default risk (γ) is calculated as the ratio of total risk-weighted assets to total non-reserve assets (L). The value for the average run-off ratio for non-equity liabilities (μ) is calculated by dividing the computed cash outflow by the total quantity of non-equity liabilities.

Table 4
Historical values for concerned parameters

Parameters	Notes	Mean	Max	Min
C/R	Capital-to-reserve ratio	1.4	3.1	0.6
Θ	Average loan maturity (month)	14	28	11
Γ	Average loan default risk	0.04	0.11	0.01
μ	Average run-off ratio for non-equity liabilities	0.21	0.22	0.19

Notes: Data for $C/R, \theta, \gamma$ are obtained from Haver Analytics. Data for μ is obtained from BvD BankFocus database.

References

Acharya, Viral V., Rajan, Raghuram, 2022. Liquidity, liquidity everywhere, not a drop to use - Why flooding banks with central bank reserves may not expand liquidity, NBER Working Papers 29680. National Bureau of Economic Research, Inc, https://doi.org/10.3386/w29680, http://www.nber.org/papers/w29680.

Albertazzi, Ugo, Nobili, Andrea, Signoretti, Federico M., 2021. The bank lending channel of conventional and unconventional monetary policy. J. Money Credit Bank. 53, 261–299.

Allen, Bill, Chan, Ka Kei, Milne, Alistair, Steve Thomas, 2012. Basel III: Is the cure worse than the disease? Int. Rev. Financ. Anal. 25, 159–166.

Altavilla, Carlo, Canova, Fabio, Ciccarelli, Matteo, 2020. Mending the broken link: Heterogeneous bank lending rates and monetary policy pass-through. J. Monetary Econ. 110, 81–98.

Angeles, Luis, 2019. On the nature of banks. Kyklos 72, 381–399.

BCBS, 2010. Basel III: A global regulatory framework for more resilient banks and banking systems. Bank for International Settlements. Technical report.

BCBS, 2013a. Basel III leverage ratio framework and disclosure requirements. Bank for International Settlements. Technical report.

BCBS, 2013b. The liquidity coverage ratio and liquidity risk monitoring tools. Bank for International Settlements. Technical report.

BCBS, 2020. Governors and heads of supervision announce deferral of Basel III implementation to increase operational capacity of banks and supervisors to respond to Covid-19. Bank for International Settlements, https://www.bis.org/press/p200327.htm.

Behn, Markus, Corrias, Renzo, Rola-Janicka, Magdalena, 2019a. On the interaction between different bank liquidity requirements. Macroprudential Bull. 9 European Central Bank.

Behn, Markus, Daminato, Claudio, Salleo, Carmelo, 2019b. A dynamic model of bank behaviour under multiple regulatory constraints. Working Paper Series 2233. European Central Bank.

Bernanke, Ben, 2007. The Financial Accelerator and the Credit Channel. https://www.federalreserve.gov/newsevents/speech/bernanke20070615a.htm.

Bernanke, Ben S., Blinder, Alan S., 1988. Credit, money, and aggregate demand. Am. Econ. Rev. 78, 435–439.

Bezemer, Dirk J., 2010. Understanding financial crisis through accounting models. Account. Org. Soc. 35, 676–688.

Bezemer, Dirk J., 2012. The economy as a complex system: The balance sheet dimension. Adv. Complex Syst. 15 1250047.

Boissay, Frédéric, Collard, Fabrice, 2016. Macroeconomics of bank capital and liquidity regulations, BIS Working Paper 467. Bank for International Settlements.

Borio, Claudio, Gambacorta, Leonardo, 2017. Monetary policy and bank lending in a low interest rate environment: Diminishing effectiveness? J. Macroecon. 54, 217–231.

Borio, Claudio EV., Farag, Marc, Tarashev, Nikola A., 2020. Post-crisis international financial regulatory reforms: A primer. BIS Working Paper 859. Bank for International Settlements.

Buckmann, Marcus, Gallego Marquez, Paula, Gimpelewicz, Mariana, 2021. The more the merrier? Evidence from the Global Financial Crisis on the value of multiple requirements in bank regulation. Staff Working Paper 905. Bank of England.

Caiani, Alessandro, Antoine, Godin, Caverzasi, Eugenio, Gallegati, Mauro, Kinsella, Stephen, Stiglitz, Joseph E., 2016. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. J. Econ. Dynam. Control 69, 375–408.

Carletti, Elena, Goldstein, Itay, Leonello, Agnese, January 2020. The Interdependence of Bank Capital and Liquidity. BAFFI CAREFIN Centre Research Paper No. 2020-128, https://doi.org/10.2139/ssrn.3523208 Available at SSRN https://ssrn.com/abstract=3523208.

Carpenter, Seth, Demiralp, Selva, 2012. Money, reserves, and the transmission of monetary policy: does the money multiplier exist? J. Macroecon. 34, 59–75.

Cecchetti, Stephen, Kashyap, Anil, 2018. What binds? Interactions between bank capital and liquidity regulations. In: Hartmann, Philipp, Huang, Haizhou, Schoenmaker, Dirk (Eds.), The Changing Fortunes of Central Banking, first ed. Cambridge University Press, pp. 192–202.

Covas, Francisco, Driscoll, John Charles, 2014. Bank liquidity and capital regulation in general equilibrium, Finance and Economics Discussion Series. Federal Reserve Board.

Diamond, William, Jiang, Zhengyang, Ma, Yiming, September 10, 2020. The reserve supply channel of unconventional monetary policy. Jacobs Levy Equity Management Center for Quantitative Financial Research Paper, https://doi.org/10.2139/ssrn.3671160 Available at SSRN https://ssrn.com/abstract=3671160.

Disyatat, Piti, 2008. Monetary policy implementation: Misconceptions and their consequences. BIS Working Paper 269. Bank for International Settlement.

Disyatat, Piti, 2011. The bank lending channel revisited. J. Money Credit Bank. 43, 711–734.

Djatche, Ngambou, Joslem, Melchisedek, 2021. Monetary policy, prudential policy, and bank's risk-taking: a literature review. J. Econ. Surv. 1–32, https://doi.org/10.1111/joes.12485.

Drechsler, Itamar, Savov, Alexi, Schnabl, Philipp, 2017. The deposits channel of monetary policy. Q. J. Econ. 132, 1819–1876.

Fender, Ingo, Lewrick, Ulf, 2016. Adding it all up: The macroeconomic impact of Basel III and outstanding reform issues. BIS Working Paper 591. Bank for International Settlements.

Forbes, Kristin, Reinhardt, Dennis, Wieladek, Tomasz, 2017. The spillovers, interactions, and (un)intended consequences of monetary and regulatory policies. J. Monetary Econ. 85, 1–22.

Fullwiler, Scott, T., 2012. An endogenous money perspective on the post-crisis monetary policy debate. Rev. Keynes. Econ. 1, 171–194.

Furfine, Craig, 2001. Bank portfolio allocation: the impact of capital requirements, regulatory monitoring, and economic conditions. J. Financ. Serv. Res. 20, 33–56.

Gambacorta, Leonardo, Marques-Ibanez, David, 2011. The bank lending channel: Lessons from the crisis. Econ. Pol. 26, 135–182.

Godley, Wynne, Lavoie, M., 2012. Monetary economics: An integrated approach to credit, money, income, production and wealth. Palgrave Macmillan.

Goel, Tirupam, Lewrick, Ulf, Tarashev, Nikola A., 2017. Bank capital allocation under multiple constraints. BIS Working Paper 666. Bank for International Settlements.

Goodhart, Charles, 2015. Why monetary policy has been comparatively ineffective? Manch. Sch. 83, 20–29.

Goodhart, Charles AE., Kashyap, Anil K., Tsomocos, Dimitrios P., Vardoulakis, Alexandros P., 2013. An integrated framework for analyzing multiple financial regulations. Int. J. Cent. Bank. 9, 109–143.

Haldane, Andrew, 2015. Multi-polar regulation. Int. J. Cent. Bank. 11, 385–401.

Haldane, Andrew, Neumann, Tobias, 2016. Complexity in regulation. In: The Palgrave Handbook of European Banking. Springer, pp. 323–347.

Hodula, Martin, Komárková, Zlatuše, Pfeifer, Lukáš, 2021. The relationship between capital and liquidity prudential instruments. J. Regul. Econ. 59, 47–70.

Jackson, Patricia, 1999. Capital requirements and bank behaviour: The impact of the Basel Accord. BIS Working Paper 1. Bank for International Settlements.

Jacob, Punnoose, Munro, Anella, 2018. A prudential stable funding requirement and monetary policy in a small open economy. J. Bank. Finance 94, 89–106.
Jakab, Zoltan, Kumhof, Michael, 2015. Banks are not intermediaries of loanable funds – and why this matters, Working Paper 529. Bank of England.
Kashyap, Anil K., Stein, Jeremy C., 1994. Monetary policy and bank lending. In: Monetary Policy. The University of Chicago Press, pp. 221–261.
Kashyap, Anil K., Stein, Jeremy C., 2000. What do a million observations on banks say about the transmission of monetary policy? Am. Econ. Rev. 407–428.
Keen, Steve, 2011. Debunking economics. In: The Naked Emperor Dethroned?, Expanded Edition. Zed Books.
Kishan, Ruby P., Opiela, Timothy P., 2000. Bank size, bank capital, and the bank lending channel. J. Money Credit Bank. 121–141.
Kopecky, Kenneth J., VanHoose, David, 2004. A model of the monetary sector with and without binding capital requirements. J. Bank. Finance 28, 633–646.
Krug, Sebastian, Lengnick, Matthias, Wohltmann, Hans-Werner, 2015. The impact of basel III on financial (in) stability: An agent-based credit network approach. Quant. Finance 15, 1917–1932.
Li, Boyao, Wang, Yougui, 2020. Money creation within the macroeconomy: An integrated model of banking. Int. Rev. Financ. Anal. 71, 101547, https://doi.org/10.1016/j.irfa.2020.101547.
Li, Boyao, Xiong, Wanting, Chen, Liujun, Wang, Yougui, 2017. The impact of the liquidity coverage ratio on money creation: A stock-flow based dynamic approach. Econ. Modell. 67, 193–202, https://doi.org/10.1016/j.econmod.2016.12.016.
Mankart, Jochen, Michaelides, Alexander, Pagratis, Spyros, 2020. Bank capital buffers in a dynamic model. Financ. Manag. 49, 473–502.
Mankiw, N Gregory, 2014. Principles Of Macroeconomics. Cengage Learning.
Martin, Antoine, McAndrews, James, Ali, Palida, Skeie, David R., 2013. Federal Reserve tools for managing rates and reserves, Staff Report 642. Federal Reserve Bank of, New York.
Martin, Antoine, McAndrews, James, David Skeie, 2016. Bank lending in times of large bank reserves. Int. J. Cent. Bank. 12, 193–222.
McLeay, Michael, Radia, Amar, Thomas, Ryland, 2014. Money creation in the modern economy, Quarterly Bulletin Q1. Bank of England.
Moore, Basil J., 1988. Horizontalists and verticalists: The macroeconomics of credit money. Cambridge University Press.
Orlowski, Lucjan T., 2015. Monetary expansion and bank credit: A lack of spark. J. Pol. Model. 37, 510–520.
Palley, Thomas I., 1994. Competing views of the money supply process: Theory and evidence. Metroeconomica 45, 67–88.
Popoyan, Lilit, Napoletano, Mauro, Roventini, Andrea, 2017. Taming macroeconomic instability: Monetary and macro-prudential policy interactions in an agent-based model. J. Econ. Behav. Organ. 134, 117–140.
Van den Heuvel, Skander, 2006. The bank capital channel of monetary policy, 2006 Meeting Papers 512. Society for Economic Dynamics.
VanHoose, David, 2007. Theories of bank behavior under capital regulation. J. Bank. Finance 31, 3680–3697.
VanHoose, David D., 2008. Bank capital regulation, economic stability, and monetary policy: What does the academic literature tell us? Atl. Econ. J. 36, 1–14.
Werner, Richard A., 2014. Can banks individually create money out of nothing? The theories and the empirical evidence. Int. Rev. Financ. Anal. 36, 1–19.
Williamson, Stephen D., 2017. Quantitative easing: How well does this tool work? St. Loise Fed, https://www.stlouisfed.org/publications/regional-economist/third-quarter-2017/quantitative-easing-how-well-does-this-tool-work.
Xing, Xiaoyun, Wang, Mingsong, Wang, Yougui, Eugene Stanley, H., 2020. Credit creation under multiple banking regulations: The impact of balance sheet diversity on money supply. Econ. Modell. 91, 720–735, https://doi.org/10.1016/j.econmod.2019.09.030.
Xiong, Wanting, Li, Boyao, Wang, Yougui, Stanley, H Eugene, 2020. The versatility of money multiplier under Basel III regulations. Finance Res. Lett. 32 101167, https://doi.org/10.1016/j.frl.2019.04.024.
Xiong, Wanting, Wang, Yougui, 2018. The impact of basel III on money creation: A synthetic analysis. Econ. Open-Access, Open-Assess. E-J. 12 (1), 20180041, https://doi.org/10.5018/economics-ejournal.ja.2018-41.