Credit defaults and credit supply under the liquidity coverage ratio

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Abstract

We build a banking dynamic model to examine the response of banks to the loan default shock under the liquidity coverage ratio (LCR) requirement. We find banks endogenously contract credit supply in response to the default shock. The boundaries in which the credit contractions take place are pointed out. In particular, one of them is presented as a default threshold above which the contraction emerges. Furthermore, the magnitudes of the credit contractions depend on the cash flow profile before and after the shock and LCR rules. Indeed, this type of contraction is an amplification to the initial adverse default shocks. This amplification mechanism along with the switch of the phases of business cycles suggests the procyclicality of the LCR regulation.

Keywords: Credit contraction, Loan defaults, Banking, Liquidity coverage ratio, Balance sheets

JEL classification: E51, G21, G28

1. Introduction

The liquidity coverage ratio (LCR) is one of the pillar of the international regulation reform for banking systems proposed by the Basel Committee on Banking Supervision (Basel Committee on Banking Supervision, 2013). The LCR requirement aims at mitigating possible liquidity shortage of banks in the stress scenario by holding sufficient high quality liquidity assets to meet liquidity needs.

But bear in mind that supplying credit is the core role banks play in the economy, affecting economy-wide activity significantly. So it is necessary to examine the supply of bank credit under the LCR requirement, the macroeconomic impact of the LCR. In particular, it is crucial to study the credit supply in bad times, especially in crisis times, where loan defaults usually become more frequent and severe. This is the reason why responses of banks to loan defaults under capital regulations have been studied profoundly (e.g., Bolton and Freixas, 2006; Furfine, 2001; Van den Heuvel, 2002). Generally, banks reduce credit supply in response to loan defaults under the capital

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regulation (Van den Heuvel, 2002). But, so far, it still lacks a definite conclusion on the change in credit supply in response to loan defaults under the liquidity regulation. So our main objective is to examine changes in the supply of bank credit under the LCR constraint when default shocks occur. Specifically, how do banks respond to loan defaults when the the liquidity regulation binds? Or how do banks subject to the LCR constraint adjust its credit supply in response to negative shocks of loan default? It calls for building the relationship between the liquidity regulation and the credit supply. This relationship may be more complex than that given by the capital regulation, because the LCR directly takes account of the cash flows but rather assets including loans as in capital requirements.

In this paper, we adopt a dynamic balance sheet model of banks to build the relationship between the LCR and credit supply. Banks supply loans subject to default risk under the LCR constraint. Obviously, as the immediate effect, banks should charge off the bad loans resulting from the defaults. Nevertheless, we find default shocks cause a knock-on effect on the bank credit supply, i.e., the following contractions in credit supply. In fact, our model describes the new relationship between bank credit risk and credit supply introduce by the LCR requirement; it results in amplifying initial default shocks.

The contraction caused by default shocks under the LCR regulation is scenario dependent and characterized by the cash flow profile of banks and the LCR rules. The dynamic banking model describes the change in balance sheets caused by the default shocks. So this model captures the endogenous contraction process. To quantitatively measure the changes in the credit supply, we use the amount of lending capacity of banks, the maximum quantity of credit supply. In case of the endogenous contractions, the ratio of the changes in the lending capacity to the size of the shocks prove to be greater than one. Otherwise, it is equal to one. Our model precisely gives the conditions for emergence and magnitude of the contractions. According to the LCR provisions, we have three different scenarios with regard to different rules of calculating the net cash outflows before and after the shocks. In two of them, banks endogenously contract credit supply in response to shocks. We point out the boundaries in which the contractions emerge, one of which appears to be a default shock threshold above which the contraction occurs. In summary, the emergence and magnitude of the contractions in credit supply are conditional upon the banking system liquidity and the LCR rules.

A more interesting and profound implication is that our result suggests that the LCR requirement may foster an adverse feedback loop between loan defaults and bank credit supply. After suffering a loan loss, banks have to actively reduce the credit supply to meet the LCR requirement. This leads to a fall in loans as a source of external funds the borrower can raise. Then more defaults on loans may take place, in turn causing more reduction in the bank lending. Under this view, the three different scenarios are connected to three different phases of business cycles, respectively. Building the link between the feedback process and the switch of the three phases, we argue the LCR regulation has the procyclical effect on credit supply. It is contrary to the policy principle of the time dimension of the macroprudential approach, such as countercyclical buffer requirements introduced under Basel III (Basel Committee on Banking Supervision, 2011; Borio, 2003, 2011).

2. Literature review

Our paper is colsely related to the papers theoretically examining the responses of the bank to the external shocks under the LCR requirement. Van den End and Kruidhof (2013) develop a liquidity stress-testing model to simulate the response of the bank complying with the LCR to the negative liquidity shocks and propose a flexible LCR requirement to strengthen the macroprudential orientation. The main difference is that we describe the response process of the bank to the default shock through the dynamics of the balance sheet, while that paper captures the reaction of the bank by a given mechanical reaction function. Balasubramanyan and VanHoose (2013) explore how the LCR constraint shapes the bank's optimal dynamic balance-sheet paths. And their paper presents the responses of loan and deposit paths to the security, loan, and deposit rate shocks respectively. This paper and our paper share some objectives. One important difference is that their approach gets the dynamic path by assuming the bank's objective is to maximize its profit, while our model do not involve the optimization behavior of the bank. Another difference is that the model does not explicitly describe the cash inflows from loan repayments, a determinant of the net cash outflows, which are the key variable and leads to three distinct scenarios as regards liquidity needs of the bank in our model.

This paper is also a related to a growing literature investigating possible impacts of the LCR regulation. Most of this literature concerns the impacts on the implementation and effect of monetary policy. Bech and Keister (2017) present the impact of the LCR requirement on interbank interest rates. Moreover, they show the LCR regulation significantly alters open market operations of the central bank. Similarly, Schmitz (2013) and Bindseil and Lamoot (2011) show the relationships and interactions between the LCR constraint on the bank and the conduct of monetary policy and then discuss the potential shifts resulting from the LCR in the effects of monetary policy. Unlike these papers, we focus on the change in credit supply of the banking system, especially the endogenous amplification mechanism in response to loan defaults caused by the LCR constraint. Arnold et al. (2012) argue that owing to the similarity between the LCR and the capital adequacy ratio proposed in Basel I, the LCR would also have the design flaw common to the capital regulation causing the procyclical effect. In addition, Li et al. (2017) have discussed the impact of the LCR on the money creation process and thus the money multiplier. By contrast, a larger literature shows the dynamics of the bank's balance sheet under the capital regulation, thus studying the credit expansion (e.g., Kopecky and VanHoose, 2004a, 2004b), the change in credit supply in response to loan defaults (e.g., Bolton and Freixas, 2006; Furfine, 2001; Van den Heuvel, 2002), and the welfare cost of capital requirements (Van den Heuvel, 2008).

Empirically, a series of works estimate impacts of the bank liquidity regulations prior to the LCR and expect to shed some light on those of the LCR owing to their similarities. Before the LCR requirement, the Basel accords do not take the liquidity regulation into account. Nevertheless, there are two notable liquidity regulations: the Dutch quantitative liquidity requirement 8028, or the Dutch liquidity coverage ratio (DLCR) in the Dutch banking system, and the individual liquidity guidance (ILG) in the UK banking system.

For the ILG, Banerjee and Mio (2017) find no evidences that the ILG leads to the shrink in the balance sheet or the reduction in bank lending. As for the DLCR, De Haan and van den End (2013a) show the bank holds a liquidity buffer more than the amount required by the DLCR. More interestingly, their paper also points out the more the capital buffer the bank maintains, the lower the liquidity buffer the bank holds. De Haan and van den End (2013b) further provide the empirical evidences that under the DLCR the bank have three types of responses to the funding liquidity shock: reducing lending, especially wholesale lending, hoarding liquidity, and engaging in fire sales. Bonner and Eijffinger (2016) find the bank sets an internal liquidity target depending on the DLCR. If below this target, the bank as a borrower demands more long-term interbank loans and raises the borrowing rate. Besides, the increase in the interbank lending rate becomes even greater if the bank below the target as a lender. Duijm and Wierts (2016) put forward another important empirical investigation as regards adjustments to the balance sheet in order to satisfy the DLCR and the behavior of the Dutch liquidity coverage ratio over the business cycle. The finding as to the former is that the bank has more incentives to adjust the liabilities instead of the liquidity assets to meet the liquidity requirement. As for the latter, they show the procyclicality of the DLCR.

3. The liquidity coverage ratio (LCR)

The liquidity difficulties banks encounter in the 2007–2008 financial crisis emphasize how crucial it is for banks to hold sufficient high liquidity assets so as to cover liquidity shortages. And it has been widely recognized that only having adequate capital is inadequate to ensure the soundness of banks. In reaction, the Basel Committee on Banking Supervision proposes the liquidity coverage ratio used for short-term liquidity management (Basel Committee on Banking Supervision, 2013). The LCR is the first international standard for bank liquidity regulation. The main objective of the LCR is to enhance resilience of banks to liquidity shocks.

The LCR requires banks to keep a sufficient stock of unencumbered high quality liquid assets $HQLA$ to cover the expected net cash outflows $NCOF$ in a 30 calendar day liquidity stress scenario. During these 30 days, we can expect regulators and supervisors can take corrective and effective actions to address the liquidity problems of banking systems.

The unencumbered high quality liquid assets contain the types of assets qualified by the LCR rules and further classed as Level 1, Level 2A, or Level 2B according to their liquidity. Level 1 assets with the highest liquidity include coins, banknotes, and central bank reserves. The liquidity of Level 2 assets is considered as being lower than Level 1 under the LCR. Typically, Level 2 assets contain corporate debt securities, covered bonds, and residential mortgage backed securities. The share of Level 2 assets is up to 40% after the application of required haircuts.

The expected net cash outflows are governed by the following formula:

$$NCOF = OF - \min\{IF, 0.75 \cdot OF\}, \quad (3.1)$$

where the OF_t and IF_t are the values of the cash outflows and inflows calculated by the LCR rules. Briefly, the cash outflows are the sum of outstanding balances of liabilities as well as off-balance sheet commitments to run off or be drawn down in the stress scenario, such as run-offs of retail deposits, unsecured wholesale funding, and secured funding. The cash inflows include contractual payments to be received by banks, such as repayments of outstanding loans and cash inflows associated with reverse repos and securities lending agreements.

Despite a newly proposed international regulation for banks, it is based on the traditional "coverage ratio" liquidity management method. According to the Basel III accord, the LCR requirement is defined as

$$\frac{HQLA}{NCOF} \geq LCR_{\min}, \qquad (3.2)$$

where $LCR_{\min}$ refers to the minimum ratio the bank must meet, gradually reaching 100% by 1 January 2019. During times of stress, banks can use the stock of HQLA to cover the cash outflows, possibly leading to the ratio below 100%. In our model, we focus on the general case in normal times where banks are expected to maintain the minimum requirement (3.2).

4. The model

This model builds on the basic framework developed in Li et al. (2017), which is in line with the standard bank liquidity management model, such as that in De Haan and van den End (2013).

4.1 Balance sheets and lending capacity

In our model, a representative bank takes deposits and makes loans. The balance sheet, and the notations, of the representative bank in period t are shown in Table 1. For simplicity, we assume the reserves and equity are constant and denote by e the ratio of the bank equity to the reserves.

Table 1
Balance sheets.

Assets		**Liabilities**	
Total loans	TL_t	Deposits	D_t
Reserves	R	Equity	E

Note that the balance sheet identity of the bank yields the basic relationship for the above four items:

$$TL_t + R = D_t + E. \quad (6.1)$$

We can build our analysis based on this highly stylized and simplified balance sheet. According to the LCR rule, only the reserves held by the bank are the qualified assets to be used as $HQLA_t$. That is,

$$HQLA_t = R. \qquad (6.2)$$

Again, according to the LCR, only deposits can raise cash outflows. Suppose that the run-off rate is μ per day and the deposit rate is 0. Denote by τ the time horizon of the LCR regulation, 30 days in the current LCR provision. The outflows are thus

$$OF_t = \tau \cdot \mu \cdot D_t, \qquad (6.3)$$

implying the outflows to be seen as an accumulation of the deposit run-off in each single day from $t+1$ to $t+\tau$.

The cash inflows take account of all the contractual repayments of the outstanding loans within the same period as the outflows. Owing to our simplified balance sheet of the bank, the repayments for outstanding loans are the only cash inflows the bank gets. We can further assume the loan rate is also 0 and consider the repayment as a function of the loan principal and of the term. Suppose, for simplicity, that the term θ is equal for all loans. Therefore, the expected repayment at period i from the loan N_j (a flow) made in period j is

$$E(RP_{ij}) = RP(i, \theta, N_j). \qquad (6.4)$$

The repayments of the loan N_j will continually be made from period $t+1$ to $t+\theta$. In addition, the repayments of loans are subject to a 50% haircut under the rule of the LCR, so that the aggregate inflows are

$$IF_t = \frac{1}{2}\sum_{i=t+1}^{t+\tau}\sum_{j=t-\theta+1}^{t} E(RP_{ij}) = \frac{1}{2}\sum_{i=t+1}^{t+\tau}\sum_{j=t-\theta+1}^{t} RP(i, \theta, N_j). \qquad (6.5)$$

Substituting the outflows (6.3) and inflows (6.5) back into the net cash outflows (3.1) and considering the assumption (6.1), we can rewrite the LCR requirement (3.2) as

$$R \ge LCR_{\min} \cdot [\tau\mu \cdot D_t - \min\{\frac{1}{2}\sum_{i=t+1}^{t+\tau}\sum_{j=t-\theta+1}^{t} RP(i, \theta, N_j), 0.75 \cdot \tau\mu \cdot D_t\}], \quad (6.6)$$

which shows how the LCR constraints the related balance sheet amounts of the bank, such as loans and deposits.

In this paper, the LCR and the stock of reserves always constrain the balance sheet size of banks and thus the credit supply. To reflect this constraint, we use the lending capapcity, a value directly connected to the size of balance sheets, to represent the credit supply. Formally, the lending capacity is defined as the maximum supply of bank loans under the LCR constraint. It takes the form of the sum of the loans on the balance sheet. Note that after making a loan, the bank continually receives the installment in each of the following θ periods; thus, the lending capacity is

$$\overline{TL}_t = \sum_{j=t-\theta+1}^{t}\sum_{i=1}^{j-(t-\theta)} RP(i, \theta, N_j); \quad (6.7)$$

At this time, the balance sheet identity becomes

$$\overline{TL} + R = D + E. \qquad (6.8)$$

4.2 Response to loan defaults

Banks are subject to the risk that borrowers fail to pay the installments, default on a loan, i.e., $E(RP_{ij})=0$. Then the uncollectible loans should be charged-off, hence reducing the stock of the total outstanding loans. Accordingly, the charge-offs CO_t are subtracted from the total outstanding loans and the equity after the shock becomes $E-CO_t$ by using the balance sheet identity (6.1). Therefore the balance sheet of banks turns out to be the form in Table 2.

Table 2
Balance sheets after charge-offs.

Assets		Liabilities	
Total loans	$TL_t - CO_t$	Deposits	D_t
Reserves	R	Equity	$E - CO_t$

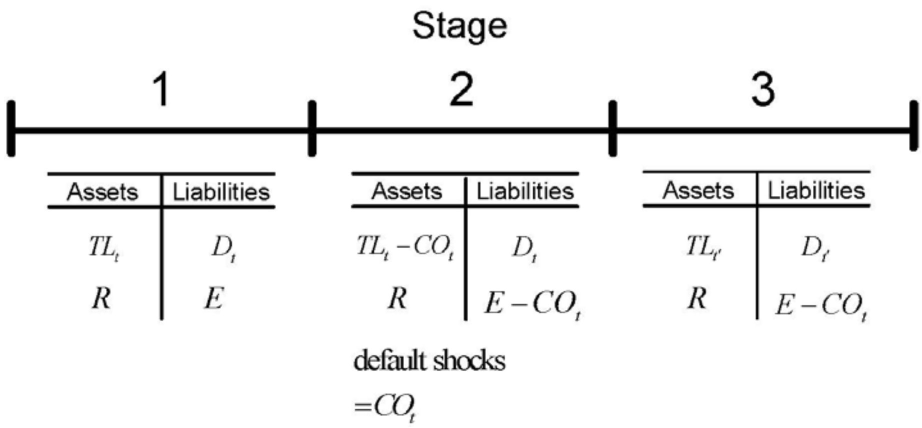

Fig. 1. Timeline.

After introducing default shocks, we can distinguish three different stages on the timeline. This can be illustrated by Fig. 1. In the first stage, there is an initial balance sheet of banks before shocks. Subsequently, in the second stage, here take place loan default shocks of size CO_t to banks. Table 2 has shown the immediate impact on the balance sheet. That is, banks should charge off the resulting nonperforming loans. So the total loans decrease to $TL_t - CO_t$, hence the equity down to $E - CO_t$. It implies a default shock not only reduces the value of the loans but also depletes the bank capital simultaneously. Finally, in the third stage, banks have completed the adjustments to the balance sheets in response to default shocks, especially the amount of credit, in order to satisfy the LCR requirement.

The credit contraction as a knock-on effect occurs between Stage 2 and Stage 3. The balance sheet in Stage 2 presents the immediate consequence of default shocks. Indeed, the change in banks' equity following default shocks lies at the root of the following banks' response, the credit contraction. The contraction refres to the change in amount of the loans banks choose to supply subject to the LCR constraint relative to that before shocks. We can quantify this change by showing the shift in the banks' lending capacity.

To examine this response, we introduce a ratio:

$$m = \frac{\overline{TL}_{t'} - \overline{TL}_t}{-CO_t}, \qquad (6.9)$$

where $\overline{TL}_t$ and $\overline{TL}_{t'}$ refer to the lending capacities before and after default shocks respectively, and $-CO_t$ represents loan default shocks. The ratio m parameterizes the lending capacity shift caused by default shocks. If only taking into account the immediate change in the loans, i.e., the charge-offs shown in Stage 2, we must have $m=1$. Therefore, any deviation from the value of 1 indicates the additional endogenous response of the supply of bank credit triggered by external default shocks.

5 Results and Discussion

5.1 The LCR constraint on the lending capacity

The bank maximizes the credit supply and finally lends up to its capacity, i.e., the maximum quantity of the credit supply. In this model, the LCR requirement limits the bank's ability to make loans. Therefore, we can obtain the value of the lending capacity by taking equality in Eq. (6.6):

$$R = LCR_{\min} \cdot [\tau\mu \cdot D_t - \min\{\frac{1}{2}\sum_{i=t+1}^{t+\tau}\sum_{j=t-\theta+1}^{t} RP(i,\theta,N_j), 0.75 \cdot \tau\mu \cdot D_t\}]. \quad (7.1)$$

To solve for the lending capacity, we make some simplifying assumptions.

First, assume for simplicity that every loan will be repaid in equal periodic installments throughout the loan's life. That is, an expected installment repaid at period i of the loan N_j granted at period j is

$$RP(i,\theta,N_j) = \frac{N_j}{\theta}. \quad (7.2)$$

Using the above expression, we can substitute the loans for the repayments. Let AL_{t+i} be the total sum of principal values of the loans at period $t+i$. Thereby, we can write the total repayments at period $t+i$ as

$$RP(t+i,\theta) = \frac{AL_{t+i}}{\theta}, \qquad (7.3)$$

so that the inflows (6.5) can be rewritten as

$$IF_t = \frac{1}{2}\sum_{i=1}^{\tau}\frac{AL_{t+i}}{\theta}. \qquad (7.4)$$

Note that, during the subsequent τ periods, the bank may continue to issue new loans N_{t+1} , $\cdots$, N_{t+i} , $\cdots$, $N_{t+\tau}$. Therefore, AL_{t+i} has the following iterative relationship:

$$AL_{t+1} = AL_t + N_t - N_{t-\theta}, \qquad (7.5)$$

which says that a new loan made at period t should be added, and a loan matured at period t removed. Further using this relationship, we can further obtain

$$AL_{t+2} = AL_{t+1} + N_{t+1} - N_{t-\theta+1} = AL_t + N_t + N_{t+1} - N_{t-\theta+1} - N_{t-\theta}$$
$$= AL_t + \sum_{j=1}^{2} N_{t+j-1} - \sum_{i=1}^{2} N_{t-\theta+i-1}, \quad (7.6)$$

$$\begin{aligned} AL_{t+3} &= AL_{t+2} + N_{t+2} - N_{t-\theta+2} \\ &= AL_{t+1} + N_{t+1} + N_{t+2} - N_{t-\theta+1} - N_{t-\theta+2} \\ &= AL_t + N_t + N_{t+1} + N_{t+2} - N_{t-\theta} - N_{t-\theta+1} - N_{t-\theta+2} \quad (7.7) \\ &= AL_t + \sum_{j=1}^{3} N_{t+j-1} - \sum_{i=1}^{3} N_{t-\theta+i-1}, \end{aligned}$$

$$\bullet\bullet\bullet$$

$$AL_{t+k} = AL_t + \sum_{j=1}^{k} N_{t+j-1} - \sum_{i=1}^{k} N_{t-\theta+i-1}. \quad (7.8)$$

Substituting Eqs. (7.5)-(7.8) into Eq. (7.4) and rearranging, we get

$$IF_t = \frac{1}{2}\sum_{i=1}^{\tau} \frac{AL_{t+i}}{\theta} = \frac{1}{2\theta} \cdot [\tau \cdot AL_t + \sum_{i=1}^{\tau} (\tau - i + 1) N_{t+i-1} - \sum_{i=1}^{\tau} (\tau - i + 1) N_{t+i-1-\theta}]. \quad (7.9)$$

Furthermore, substituting the above cash inflows and the cash outflows (6.3) into the LCR constraint (7.1), we get

$$\begin{aligned} R &= LCR_{\min} \cdot [\tau\mu \cdot D_t \\ &- \min\{\frac{1}{2\theta} \cdot (\tau \cdot AL_t + \sum_{i=1}^{\tau} (\tau - i + 1) N_{t+i-1} - \sum_{i=1}^{\tau} (\tau - i + 1) N_{t+i-1-\theta}), 0.75 \cdot \tau\mu \cdot D_t\}]. \end{aligned} \quad (7.10)$$

Secondly, suppose, for analytic simplicity, that the size of the loan default shock is a fraction ω of the lending capacity before the shock, i.e.,

$$CO_t = \omega \cdot \overline{TL}_t. \quad (7.11)$$

Practically, it is easy to obtain the net charge-off rate b_t defined as the ratio of charged-off loans minus recoveries on them to the outstanding loans, that is,

$$b_t = \frac{CO_t}{TL_t}. \quad (7.12)$$

This implies the relationship between ω and the net charge-off rate b_t:

$$\omega = b_t \cdot \frac{TL_t}{\overline{TL}_t}. \quad (7.13)$$

Indeed, the above formula gives a definition of the variable ω in the Eq. (7.11).

Lastly, to simplify the calculation for the lending capacity, without loss of generality, we assume the bank approaches its lending capacity by issuing a series of equal new loans $N_t(N_{t'})$ before (after) the shock. Thus, the lending capacities defined by Eq. (6.7) before and after the shock respectively reduce to

$$\overline{TL}_t = \frac{(1+\theta)}{2} \cdot N_t \quad (7.14)$$

and

$$\overline{TL}_{t'} = \frac{(1+\theta)}{2} \cdot N_{t'}. \qquad (7.15)$$

Substituting the lending capacity before the shock (7.14) and after the shock (7.15) and the loan default shock (7.11) into the ratio (6.9), we can rewrite it as

$$m = \frac{N_{t'} - N_t}{-\omega \cdot N_t}. \qquad (7.16)$$

Now back to the LCR requirement. It has two distinct calculation methodologies with regard to the net cash outflows. On the one hand, boundary condition being $IF_t \geq 0.75 \cdot OF_t$, the expression of the net cash outflows is

$$NCOF_t = 0.25 \cdot OF_t. \quad (7.17)$$

On the other hand, when $IF_t < 0.75 \cdot OF_t$, the form of the net cash outflows is

$$NCOF_t = OF_t - IF_t, \quad (7.18)$$

Similarly, we must have two symmetric expressions as regards the net cash outflows after the shock, i.e.,

$$NCOF_{t'} = 0.25 \cdot OF_{t'} \quad (7.19)$$

and

$$NCOF_{t'} = OF_{t'} - IF_{t'}. \quad (7.20)$$

As shown in Table 3, we have three possible scenarios defined by the combinations of above different expressions before and after the shock respectively except the scenario of $IF_t < 0.75 \cdot OF_t$ with $IF_{t'} \geq 0.75 \cdot OF_{t'}$ because the shock leads to a decrease in the repayments and thus the inflows. In what follows, we will show each solution for these three scenarios.

Table 3
Possible scenarios.

	Before the shock	**After the shock**
Scenario 1	$IF_t \geq 0.75 \cdot OF_t$	$IF_{t'} \geq 0.75 \cdot OF_{t'}$
Scenario 2	$IF_t \geq 0.75 \cdot OF_t$	$IF_{t'} < 0.75 \cdot OF_{t'}$
Scenario 3	$IF_t < 0.75 \cdot OF_t$	$IF_{t'} < 0.75 \cdot OF_{t'}$

5.2 Scenario 1

In this scenario, according to the definition of the net cash outflows (7.17), the LCR constraint (7.10) turns out to be

$$R = 0.25 \cdot LCR_{\min} \cdot \tau\mu \cdot D_t. \qquad (7.21)$$

That is, the net cash outflows prove to be one-quarter of the cash outflows; hence, the LCR constraint (7.10) solely depends on the deposits. Consequently, it makes the calculation relatively simple. Using the bank balance sheet identity (6.8) to substitute for the deposits, we get the LCR constraint before the shock:

$$R = 0.25 \cdot LCR_{\min} \cdot \tau\mu(\overline{TL}_t + R - E). \quad (7.22)$$

After the shock, there is the same expression of $NCOF_{t'}$ (7.19) as before the shock.

So, just to take $E \to E-\omega\cdot\overline{L}_t$, we get the corresponding net cash outflows after the shock:

$$R=0.25\cdot\tau\mu(\overline{TL}_{t'}+R-(E-\omega\cdot\overline{TL}_t)). \quad (7.23)$$

Substituting Eqs. (7.14) and (7.15) into Eqs. (7.22) and (7.23), we obtain

$$\begin{cases} R=0.25\cdot LCR_{\min}\cdot\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_t+R-E), \\ R=0.25\cdot LCR_{\min}\cdot\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_{t'}+R-(E-\omega\cdot\dfrac{(1+\theta)}{2}\cdot N_t)). \end{cases} \quad (7.24)$$

Simple calculation yields that

$$\begin{cases} N_t=\dfrac{R\cdot\left(8+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)\right)}{LCR_{\min}\cdot\tau\mu(1+\theta)}, \\ N_{t'}=\dfrac{R\cdot\left(8+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)-\omega\cdot\left(8+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)\right)\right)}{LCR_{\min}\cdot\tau\mu(1+\theta)}. \end{cases} \quad (7.25)$$

Substituting the above into the definition of m (7.16), we have $m=1$.

We can understand this result intuitively. In this scenario, the net cash outflows the constraint requires can be reduced to rely only on the cash outflows determined by the stock of bank deposits rather than by loans and their defaults. So the shock cannot generate any impacts on the bank credit supply in this scenario.

5.3 Scenario 2

As to this scenario, the cash inflows are greater or equal to three-quarters of the cash outflows before the shock and less than after the shock instead. Thus, unlike Scenario 1, we have two different expressions on the net cash outflows and thus two different forms of the constraint in the stages before and after the shock. Specifically, before the shock, the constraint is the same as in the Scenario 1:

$$R=0.25\cdot LCR_{\min}\cdot\tau\mu(\overline{TL}_t+R-E). \quad (7.26)$$

On the other hand, after the shock, the corresponding net cash outflows prove to be (7.20). Therefore, the constraint (7.10) turns out to be

$$R=LCR_{\min}\cdot(\tau\mu\cdot D_{t'}-\frac{1}{2\theta}\cdot\tau\cdot AL_{t'}). \quad (7.27)$$

Despite the difference in the constraints the bank faces between before and after the shock, the shock still leads to the equity changing from E to $E-\omega\cdot\overline{L}_t$. Furthermore, using the balance sheet identity (6.8) and $AL_{t'}=\theta\cdot N_{t'}$ and substituting Eqs. (7.14) and (7.15) for the lending capacities, we get

$$\begin{cases} R=0.25\cdot LCR_{\min}\cdot\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_t+R-E), \\ R=LCR_{\min}\cdot(\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_{t'}+R-(E-\omega\cdot\dfrac{(1+\theta)}{2}\cdot N_t))-\dfrac{\tau}{2}\cdot N_{t'}). \end{cases} \quad (7.28)$$

Solving, we find the loans the bank chooses to make before and after the shock are respectively

$$\begin{cases} N_t = \dfrac{R\cdot\left(8+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)\right)}{LCR_{\min}\cdot\tau\mu\left(1+\theta\right)}, \\ N_{t'} = \dfrac{R\cdot\left(2+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)-\omega\cdot\left(8+LCR_{\min}\cdot\tau\mu\left(-2+2e\right)\right)\right)}{LCR_{\min}\cdot\tau\left(-1+\mu+\theta\mu\right)}. \end{cases} \quad (7.29)$$

Again, substituting the above into Eq. (7.16), we obatin

$$m=1+\frac{4+\mu\left(-3-3\theta+LCR_{\min}\cdot\tau\left(-1+e\right)\right)}{-\omega\cdot\left(-1.+\mu+\theta\mu\right)\left(4+LCR_{\min}\cdot\tau\mu\left(-1+e\right)\right)}+\frac{1}{\left(-1+\mu+\theta\mu\right)}. \quad (7.30)$$

Significantly, we can prove $m>1$ in this scenario.

Recall that the boundary conditions before and after the shock, as shown in the two top rows in Table 3. On the one hand, the boundary condition for Scenario 2 before the shock is $IF_t \geq 0.75\cdot OF_t$, the same as Scenario 1. By expanding and rearranging $IF_t \geq 0.75\cdot OF_t$, we obtain

$$4+\mu\left(-3-3\theta+LCR_{\min}\cdot\tau\left(-1+e\right)\right)\geq 0. \quad (7.31)$$

On the other hand, there are two distinct boundary conditions for Scenario 2 and Scenario 1 after the shock, i.e., $IF_{t'} < 0.75\cdot OF_{t'}$ and $IF_{t'} \geq 0.75\cdot OF_{t'}$ respectively. Accordingly, we can specify a critical size ω_c of the shock above which the cash inflows drop to the outflows, i.e., $IF_{t'} = 0.75\cdot OF_{t'}$. It represents the boundary between Scenario 2 and Scenario 1. Combining $IF_{t'} = 0.75\cdot OF_{t'}$ and Eq. (7.28), we have

$$\begin{cases} \dfrac{\tau\cdot N_{t'}}{2} = 0.75\cdot\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_{t'}+R-(E-\omega_c\cdot\dfrac{(1+\theta)}{2}\cdot N_t)), \\ R = 0.25\cdot LCR_{\min}\cdot\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_t+R-E), \\ R = LCR_{\min}\cdot(\tau\mu(\dfrac{(1+\theta)}{2}\cdot N_{t'}+R-(E-\omega\cdot\dfrac{(1+\theta)}{2}\cdot N_t))-\dfrac{\tau}{2}\cdot N_{t'}), \end{cases} \quad (7.32)$$

which implies

$$\omega_c = 1-\frac{\mu\left(3+3\theta\right)}{4+LCR_{\min}\cdot\tau\mu\left(-1+e\right)}. \quad (7.33)$$

As we know, the loan default reduces the repayments and thus the cash inflows. The distinction between Scenario 1 and Scenario 2 can be explained as follows. When the size of the shock is below or equal to the threshold ω_c, i.e., $\omega\leq\omega_c$, the reduction in the cash inflows from the default loans has not yet caused it to drop to the value of the outflows; we are in Scenario 1. Otherwise, if above the threshold, i.e., $\omega>\omega_c$, the loan default shock is so large that the inflows become less than the outflows after the shock; we are in Scenario 2.

Using $\omega>\omega_c$, together with Eq. (7.31), we have

$$\frac{4+\mu\left(-3-3\theta+LCR_{\min}\cdot\tau\left(-1+e\right)\right)}{-\omega\cdot\left(-1+\mu+\theta\mu\right)\left(4+LCR_{\min}\cdot\tau\mu\left(-1+e\right)\right)}+\frac{1}{\left(-1+\mu+\theta\mu\right)}>0. \quad (7.34)$$

So we finally get the proof of $m > 1$. In this sense, the value of ω_c represents the critical value at which the credit contraction begins to emerge.

Furthermore, if expanding the boundary condition $IF_{t'} < 0.75 \cdot OF_{t'}$, we obtain

$$\frac{R \cdot \left(1 + \mu\left(-0.75 - 0.75\theta + LCR_{\min} \cdot \tau\left(-0.25 + 0.25e\right)\right)\right) - R \cdot \omega\left(1 + LCR_{\min} \cdot \tau\mu\left(-0.25 + 0.25e\right)\right)}{LCR_{\min}\left(-1 + \mu + \theta\mu\right)} < 0. \quad (7.35)$$

Note that ω must be greater than the value of ω_c, so that

$$\begin{aligned} &1 + \mu\left(-0.75 - 0.75\theta + LCR_{\min} \cdot \tau\left(-0.25 + 0.25e\right)\right) \\ &-\omega\left(1 + LCR_{\min} \cdot \tau\mu\left(-0.25 + 0.25e\right)\right) < 0, \end{aligned} \quad (7.36)$$

which says the numerator of the left-hand side of Eq. (7.35) is negative. Therefore, the denominator must be positive, i.e.,

$$\left(-1 + \mu + \theta\mu\right) > 0. \quad (7.37)$$

We calculate the derivative of the ratio m with respect to ω:

$$\frac{dm}{d\omega} = \frac{4 + \mu\left(-3 - 3\theta + LCR_{\min} \cdot \tau\left(-1 + e\right)\right)}{\omega^2 \cdot \left(-1 + \mu + \theta\mu\right)\left(4 + LCR_{\min} \cdot \tau\mu\left(-1 + e\right)\right)}; \quad (7.38)$$

using Eqs. (7.31) and (7.37), together with $4 + LCR_{\min} \cdot \tau\mu\left(-1 + e\right) > 0$ (because $0 < LCR_{\min} \le 1$, $0 \le \tau\mu \le 1$, and $e \ge 0$), we can prove

$$\frac{dm}{d\omega} \ge 0, \quad (7.39)$$

which implies the ratio is increasing in ω, or in the net charge-off rate b. That is, the more loan losses the bank suffers, the greater the endogenous reduction in the bank credit supply.

5.4 Scenario 3

As for this scenario, the cash inflows both before and after the shock are less than three-quarters of the cash outflows. The calculations of the net cash outflows before and after the shock are in accordance with Eq. (7.18) and (7.20) respectively. So the LCR constraints before the shock is

$$R = LCR_{\min} \cdot (\tau\mu \cdot D_t - \frac{1}{2\theta} \cdot \tau \cdot AL_t); \quad (7.40)$$

symmetrically, after the shock, we have

$$R = LCR_{\min} \cdot (\tau\mu \cdot D_{t'} - \frac{1}{2\theta} \cdot \tau \cdot AL_{t'}). \quad (7.41)$$

Following a similar analysis as in Scenario 1 and Scenario 2, we obtain the final constraint for this scenario:

$$\begin{cases} R = LCR_{\min} \cdot (\tau\mu(\frac{(1+\theta)}{2} \cdot N_t + R - E) - \frac{\tau}{2} \cdot N_t), \\ R = LCR_{\min} \cdot (\tau\mu(\frac{(1+\theta)}{2} \cdot N_{t'} + R - (E - \omega \cdot \frac{(1+\theta)}{2} \cdot N_t)) - \frac{\tau}{2} \cdot N_{t'}). \end{cases} \quad (7.42)$$

Solve for N_t and $N_{t'}$ to obtain

$$\begin{cases} N_t = \dfrac{2R\left(1+LCR_{\min}\cdot\tau\mu\left(-1+e\right)\right)}{LCR_{\min}\cdot\tau\left(-1+\mu+\theta\mu\right)}, \\ N_{t'} = \dfrac{2TR\left(-1+\mu\left(1-\omega\right)\left(1+\theta\right)\right)\left(1+LCR_{\min}\cdot\tau\mu\left(-1+e\right)\right)}{LCR_{\min}\cdot\tau\left(-1+\mu+\theta\mu\right)^2}. \end{cases} \quad (7.43)$$

Again, substitute the above into Eq. (7.16) to get

$$m = 1 + \frac{1}{-1+\mu+\theta\mu}. \quad (7.44)$$

In what follows, we can prove $m > 1$ in this scenario. Expanding and rearranging the boundary condition before the shock for this scenario, $IF_t < 0.75 \cdot OF_t$, we obtain

$$\frac{R\left(1+\mu\left(-0.75-0.75\theta+LCR_{\min}\cdot\tau\left(-0.25+0.25e\right)\right)\right)}{LCR_{\min}\cdot\left(-1+\mu+\theta\mu\right)} < 0. \quad (7.45)$$

At the same time, we have known the boundary condition for Scenario 1 and Scenario 2 before the shock, $IF_t \geq 0.75 \cdot OF_t$, can be expressed by Eq. (7.31). Therefore, the boundary condition for Scenario 3 as a violation of Eq. (7.31) corresponds to the left-hand side of it less than zero:

$$4+\mu\left(-3-3\theta+LCR_{\min}\cdot\tau\left(-1+e\right)\right) < 0. \quad (7.46)$$

It implies the denominator of the left-hand side of Eq. (7.45) is greater than zero, i.e.,

$$LCR_{\min}\cdot\left(-1+\mu+\theta\mu\right) > 0, \quad (7.47)$$

where $LCR_{\min} > 0$, and we then have $\left(-1+\mu+\theta\mu\right) > 0$. That is, the second term of the right-hand side of Eq. (7.44) proves to be greater than zero; therefore, we get $m > 1$.

5.5 Discussion

We have shown the response of the lending capacity to the loan default shock in each possible scenario. In the last two scenarios, the net cash outflows dependent on the inflows and thus the amount of loans held by banks, the ratioes of the reduction in the lending capacity to the default shock prove to be greater than 1. As we have mentioned before, if the ratio is greater than 1, the impact of the shock to the credit supply will be more than the shock itself—the emergence of the endogenous reduction in the supply following the shock.

Banks suffering a loan loss causes not only the corresponding immediate decline in the volume of bank credit but also the potential following drop in the supply of bank credit. This result indicates the LCR requirement amplifies the initial default shock in such a way that banks cut lending in response to the shock when the LCR requires banks to meet the liquidty needs in the stress scenario.

More importantly, there is an adverse feedback loop between loan defaults and credit supply. The loan default leads to the undesired endogenous amplification to the initial shock, causing an unexpected decrease in the bank credit as a source of external funds the borrowers can obtain. This adversely affects their repayment performance; hence more defaults on the outstanding loans, or more default shocks, occur. Consequently, it turns out to be an adverse feedback loop: loans defaulting and credit supply reducing are mutually reinforcing. This result is an undesired departure from the objective of the LCR requirement proposed by Basel III.

Thus, considering the above amplification mechanism, we can show the procyclicality of the LCR regulation via the results of the three scenarios. Consistent with the LCR rules, the inflows greater or equal to three-quarters of the cash outflows can be seen as a criterion that banks have an adequate cash inflows and thus with low liquidity needs and risk. So Scenario 1, Scenario 2, and Scenario 3 respectively represent banks meeting the criterion both before and after the shock, only before the shock, and neither before nor after the shock. In this regard, from Scenario 1 to Scenario 3 can respectively be related to the three distinct successive phases of the business cycle: the boom phase (good times), the peak of the boom (transition from good to bad times), and the bust phase (bad times) (Drehmann, Borio, Gambacorta, Jiménez, & Trucharte, 2010; Drehmann, Borio, & Tsatsaronis, 2011). The LCR regulation creates the procyclical effect on credit supply across these three states of the cycle.

Suppose that the cash inflows and outflows of banks satisfy $IF_t \geq 0.75 \cdot OF_t$, and the shock is below the threshold ω_c. This means we are in Scenario 1, the boom phase, where banks have an adequate cash inflows relative to the outflows; the default shock does not generate any impacts except banks charging off those resulting bad loans. In other words, a loan default shock below the threshold is not able to cause the following contraction in the bank credit supply. During the boom phase, the banks' credit and balance sheet expand, usually resulting in an increase in the loan default rate (Van den Heuvel, 2002). Once greater than threshold ω_c, the default shock plunges the banking system into Scenario 2, the peak of the boom. In the present scenario, the default shock induces the amplification, the endogenous reduction in the supply of bank credit, thus tightening credit availability to the borrrowers. And then it reduces their abilities for repayments, hence the decrease in the cash inflows. In this sense, the default shock threshold can be used to identify whether the contraction in credit supply takes place when banks are subject to the LCR constraint. Put differently, it turns out to be also the critical value to distinguish the above two different states of the cycle. After the transition from good to bad times, banks have been in the stage where $IF_t < 0.75 \cdot OF_t$. It implies the banking system is now in the first stage of Scenario 3, the bust phase. In this scenario, a default shock causes the following reduction in the bank credit supply whenever occurring.

In summary, in the boom state, the loan default does not cause the credit contraction. On the contrary, in either the transition or the bust phase, the default leads to the following credit contraction, thereby magnifying the downswing. So this is the procyclical effect resulting from the LCR regulation on credit supply.

6 Conclusions

The LCR as a new liquidity regulation requires the bank to hold sufficient high quality liquid assets to mitigate liquidity risk. Besides this original objective, it may generate the effect on credit supply, the central function of the banking system in an economy. In this article, we build a banking balance-sheet model to examine how the loan default shock impacts the supply of bank credit under the LCR regulation. Obviously, the loan default leads to the bank charging off the corresponding bad loans.

We, however, find this immediate consequence triggers a following contraction in the credit supply when the LCR binds. The charge-offs cause the simultaneous decreases in loans and equity; they change the balance sheet and thus the cash flow profile. In order to meet the LCR requirement, the bank has to actively adjust its balance sheet in response to the change. Thus, the bank may reduce the credit supply.

Quantitatively, we define a ratio of the change in the lending capacity to the exogenous shock to measure the credit contraction. It equals one if here are only the charge-offs. According to the LCR, there are two rules to calculate the net cash outflows corresponding to whether the inflows are greater than the three-quarters of the outflows. The charge-off of loans reducing the cash inflows may change the way to calculate the net cash outflows. So there are three different scenarios corresponding to different combinations of the ways to calculate the net cash flows before and after the shock. We obtain all the ratios in the three scenarios, respectively. Importantly, the ratio proves to be greater than one in the scenario when the net cash outflows either before or after the shock depend on loans, thus affected by default shocks. Two of the scenarios satisfy this condition. Their boundaries are shown. One of them between the scenario without the contraction and with the contraction can be expressed as a default shock threshold.

More interestingly, we can consider the three scenarios as the three different phases of the business cycle, thereby pointing out the procyclicality of the LCR. That is, the liquidity regulation for addressing the liquidity problem of banking systems creates a procyclical effect on credit supply. As a result, the LCR reinforces the procyclicality of banking systems. It conflicts with the policy principle of the time dimension of the macroprudential approach like the countercyclical buffer proposed under Basel III.

The model we develop in this article is also suitable for studying some other valuable and more complex topics. For example, by further taking into account securities held by the bank, it can be used to investigate how banks adjust the balance sheet in response to the shock to the security price under liquidity or capital regulations.

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