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Bank equity, interest payments, and credit creation under Basel III regulations[⋆,⋆⋆]

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Abstract

Both equity and regulation play key roles in determining the ability of credit creation of banks. The equity endogenously varies while the regulations are exogenously imposed. I propose a banking model to investigate how the changes in bank equity due to interest receipt and expenditure affect credit and money creation under the Basel III regulations. Three Basel III regulations are discussed: the capital adequacy ratio, liquidity coverage ratio, and net stable funding ratio. The effects on credit creation are demonstrated by the changes in the credit supply in response to the interest payments changing the equity. My results indicate that the changes in equity cause multiplier effects on the credit supply. The multipliers depend on the regulatory constraints. Similarly, I present the impacts on money creation, given by the multiplier effects on the money supply. This study sheds considerable light on how bank equity and Basel III regulations affect credit and money creation.

Keywords: Credit creation, Basel III, Bank equity, Interest payments, Multiplier effect, Balance sheet

JEL classification: E51, G21, G28, G32

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1. Introduction

As Adrian and Shin (2010a,b, 2011) point out, banks' equity behaves as a predetermined variable and it affects their future credit creation. Every day, the equity changes due to interest income and expenses. In response to such changes, banks adjust their credit creation. However, the adjustments must be subject to bank regulation. I focus on three regulations introduced under the Basel III Accord. Basel III introduced improved capital regulations and new liquidity regulations: the capital adequacy ratio (CAR) (Basel Committee on Banking Supervision, 2011), liquidity coverage ratio (LCR) (Basel Committee on Banking Supervision, 2013), and net stable funding ratio (NSFR) (Basel Committee on Banking Supervision, 2014b).[1] Banks comply with one of the capital or liquidity regulations, either the CAR, LCR, or NSFR. This raises the question of how do such changes in bank equity resulting from interest payments affect credit creation under the regulations?

To address this issue, I present a banking model in which banks comply with regulations and create credit while receiving and paying interest. Following Adrian and Shin (2010a,b, 2011); Bezemer (2010); McLeay et al. (2014), the model developed for this study is based on banks' balance sheets. Banks expanding or contracting their balance sheets means their creating or destroying credit. Starting with a predetermined amount of equity, banks expand or contract their balance sheets to maximize their profits while the expansions and contractions are limited by the regulations placed upon them. Using a bank balance sheet, a regulation becomes a regulatory relationship imposed on the balance sheet quantities. Combining the equity and regulatory relationship determines the amount of credit banks can create, i.e., the credit supply.

[1]Additionally, Basel III introduces two capital regulations: the CAR and the leverage ratio (Basel Committee on Banking Supervision, 2014a). The CAR is the risk-based capital regulation while the leverage ratio is the non-risk-based capital regulation. The non-risk-based leverage ratio is not discussed in this study because if the risk weights for loans and securities take the value of one, the results of the leverage ratio are the same as those of the CAR.

Then, I consider the receipt and expenditure as interest payment shocks that change equity. After interest payment shocks impact the equity, banks must adjust their balance sheets to again maximize their profits. This adjustment or response to shocks must follow the regulation through the corresponding regulatory relationship by which the equity that was changed by the interest payment shocks then determines the next credit supply. The differences between the credit supply before and after the interest payment shocks demonstrate their effects on credit creation under the regulations.

First, under each regulation, I answer whether the bank credit supply increases or decreases when interest payment shocks increase the equity. Second, I discover the interest payment shocks cause multiplier effects on the credit supply: the absolute value of the changes in the credit supply can be expressed as the size of the shocks multiplied by the multipliers. Such multiplier effects arise from (i) the ability of banks to expand and contract their balance sheets and (ii) this ability being limited by regulations. For each regulation, two main findings are as follows.

When banks are subject to the CAR, the increases in equity increase the credit supply. Furthermore, the CAR leads to a multiplier greater than one and the interest payment shocks to the equity are amplified. The value of the multiplier is then the reciprocal of the product of the required capital ratio and the risk weight for loans. The intuition is that increases in the required capital ratio or the risk weight decrease loans, thus reducing the difference between them.

In contrast with the CAR, the LCR leads to fourfold links between the changes in equity and the credit supply, and increases in the equity can either increase or decrease the credit supply. According to Basel Committee on Banking Supervision (2013), the LCR has two different regulatory regimes: inflows greater than or equal to three-quarters of outflows (labeled State H) and inflows less than three-quarters of outflows (labeled State L). The LCR regimes can switch due to the interest payment shocks to the equity. As a result, the discussion of the LCR consists of four cases: (i) State H before and after interest payments (denoted Case HH), (ii) State L before and after interest payments (denoted Case LL), (iii) State L before and State H after interest payments (denoted Case LH), and (iv) State H before and State L after interest payments (denoted Case HL). In Cases HH, LL, and LH, the increases in equity increase the credit supply. On the contrary, in Case HL, the increased equity decreases the credit supply.

In Cases HH and LH, the multipliers are exactly one and the interest payment shocks to the equity equal the changes in credit supply. In Case LL, the multiplier is greater than one and thus the equity changes are amplified. In Case HL, the multiplier can be greater or less than one and the equity changes are either amplified or contracted. To discuss the multipliers in greater detail, I define two variables: the marginal inflow of loans and the marginal outflow of deposits. The marginal inflow of loans is defined as the derivative of cash inflows with respect to loans and the marginal outflow of deposits is the derivative of cash outflows with respect to deposits. The multipliers depend only on the ratio of the marginal inflow of loans to the marginal outflow of deposits. This ratio can be a valid way to assess the liquidity of banks. In Case LL, the multiplier is increasing in the ratio and the increase in the liquidity of banks increases the amplification of the shocks. In Case HL, the multiplier is decreasing in the ratio: the increase in the liquidity either decreases the amplification or increases the contraction of the shocks.

When banks are subject to the NSFR, the links between the changes in the equity and those in the credit supply come in two forms. Increases in the equity can increase the credit supply if the product of the required NSFR and the required stable funding (RSF) factor for loans is greater than the available stable funding (ASF) factor for deposits. Otherwise, such increases can reduce the credit supply.

The two multipliers range from fewer than one to greater than one. Here, the NSFR can cause either amplification or contraction of the interest payment shocks to the equity. The multipliers rely on a specific ratio: the numerator is the RSF factor for loans multiplied by the required NSFR and subtracted from one; the denominator is the ASF factor for deposits subtracted from one. Next I relate these multipliers to the liquidity of banks. This is most readily observable by considering the special case in which the required NSFR takes the value of one, as Basel III requires. The ratio becomes a measurement of the liquidity of banks by the ASF factor and RSF factor. The numerator is increasing in the liquidity of loans while the denominator is decreasing in the stability of deposits. The following findings offer insight into the two multipliers. On the one hand, if the RSF factor is greater than the ASF factor, the multiplier is greater than or equal to one. When the liquidity of banks measured by the ratio increases, the multiplier and the amplification of the shocks increase. On the other hand, if the RSF factor is less than the ASF factor, the multiplier can be either greater or smaller than one. Ultimately, an increase in the liquidity decreases the multiplier, thus decreasing the amplification or increasing the contraction of the shocks.

So far I have shown the multiplier effects on the credit supply, which determine the impacts on credit creation. As (Bezemer, 2010; Li and Wang, 2020; Jakab and Kumhof, 2015; McLeay et al., 2014; Werner, 2014a,b, 2016) argue, banks creating or destroying credit implies their creating or destroying money at the same time and by the same amount. Thus the money supply can also be obtained, and the responses of the money supply to interest payment shocks demonstrate the effects on money creation. By the balance sheet identity, the responses of the money supply are given by the multiplier effects on it.

These results offer three main policy implications. First, my model reveals what roles the parameters introduced by the regulations, play in banks' adjusting the credit supply, in response to interest payments. In particular, the adjustments of the credit supply under regulations are linked to their stringency. These findings can help policymakers control the volatility of the credit supply due to interest payments by adjusting their regulations. Second, my results concerning the LCR and NSFR offer policymakers a better understanding of the relationship between the liquidity of banks and the supply of credit. Third, my results are helpful for policymakers to see how the policy interventions that influence the interest income or expenses of banks affect the credit and money supply under the regulations.

Related literature. My paper belongs to the literature that develops theoretical banking models to examine effects of bank regulations. Since Basel I was implemented, the effects of the CAR on bank credit supply have received considerable attention.[2] In this literature, most closely related to my work, is that which discusses the relationships between bank equity and credit supply under the CAR. Kopecky and VanHoose (2004) devise a model to discuss how banks who comply with the CAR maximize their profits subject to the cost of adjusting their balance sheets. They reveal both the credit supply with the equity given exogenously and the credit supply with the equity determined endogenously. Zhu (2008) introduces shocks to the interest revenues and thus the equity when banks comply with the CAR. He compares the equity ratios and the probability of bank failure with a higher loan return to those with a lower loan return. Hyun and Rhee (2011) find that to increase the equity ratios under the CAR, banks prefer to reduce loans rather than issue new equity. Van den Heuvel (2007) shows that the capital position of banks affects their credit supply: the decrease in the equity, resulting from an increase in deposit rates, reduces the credit supply under the CAR.

More recent papers consider the impact of liquidity regulations on the credit supply. Balasubramanyan and VanHoose (2013) investigate the optimal dynamic paths of loans and deposits under the LCR or the LCR coupled with the CAR. They discover that increases in loans and deposits are caused by rises in the spread between security and deposit rates or between loan and security

[2]The basic verdict is that the increase in the stringency of the CAR causes a significant fall in the credit supply (Francis and Osborne, 2009; Furfine, 2001; Stiglitz and Greenwald, 2003). Recently, De Nicolo et al. (2014) find an inverted U-shaped relationship between the credit supply and the stringency of the CAR. Another branch of this literature examines the procyclical effect on the credit supply caused by the CAR (e.g., Estrella (2004); Heid (2007)). For a survey of this literature, see Martynova (2015); VanHoose (2007).

rates when banks are subject to the LCR. Similar to Zhu (2008), De Nicolo et al. (2014) also introduce the shocks to the interest revenues of banks. These authors discuss the effects of the CAR and LCR on lending and they reveal that when banks comply with the CAR, the addition of the LCR leads to a significant reduction in lending. Schmaltz et al. (2014) present numerical solutions that address banks' profit maximization problems subject to the four joint Basel III regulations, the CAR, leverage ratio, LCR, and the NSFR. They suggest that banks respond to these regulations mainly by managing their debts and equities with few changes in loans. Birn et al. (2017) discuss the changes in banks' balance sheets to fulfill the same joint Basel III regulations. They conclude that banks increase their equity to meet the CAR or leverage ratios, increase high-quality liquid assets to meet the LCR, and raise the ASF factors to meet the NSFR.[3]

I contribute to this literature by developing an analytical framework that captures the dynamics of balance sheets of banks under the Basel III capital and liquidity regulations. This framework presents the explicit links between equity changes resulting from interest payment shocks and the changes in the credit supply under the Basel III regulations. Moreover, this framework allows the inclusion of more detailed descriptions of the LCR. Analyses conducted by Balasubramanyan and VanHoose (2013); De Nicolo et al. (2014); Schmaltz et al. (2014) consider only one regulatory regime of the LCR. In fact, the LCR has two regulatory regimes that are determined by the cash flow positions of banks. My study considers the two LCR regulatory regimes and discusses the different combinations of the regimes before and after interest payment shocks. The credit supplies associated with these combinations are significantly different

[3]Several papers also use theoretical banking models to exhibit the other effects that arise from liquidity regulations, such as the LCR impact on the interbank rates (Bech and Keister, 2017), prices of the securities qualified as high-quality liquid assets (Fuhrer et al., 2017), systemic risks measured by bank defaults (Aldasoro and Faia, 2016), the resilience of banks (König, 2015), and the NSFR influence on the debt maturity of banks (Wei et al., 2017).

from each other. My results also show the consequent effects of when regimes switch due to shocks.

Related to my modeling approach, Adrian and Shin (2010a,b, 2011) depict the expansion and contraction of the balance sheets of financial intermediaries. Birn et al. (2017); Schmaltz et al. (2014) simulate the adjustments of the bank balance sheets to fulfill the Basel III regulations.[4] Li and Wang (2020); McLeay et al. (2014); Werner (2014b) employe the balance sheets of banks to illustrate the accounting details of credit and money creation. Based on these accounting frameworks, Li et al. (2017); Xing et al. (2020); Xiong et al. (2020) place bank balance sheets at the heart of the models to explore credit and money creation under the Basel III regulations. My paper extends the modeling approaches of Li and Wang (2020); Li et al. (2017); McLeay et al. (2014); Werner (2014b); Xing et al. (2020); Xiong et al. (2020) by describing the adjustments of bank balance sheets in reaction to changes in equity resulting from interest payments. Furthermore, compared to Li et al. (2017); Xing et al. (2020); Xiong et al. (2020), my study incorporates loan and deposit rates in the Basel III regulatory constraints. I then present the changes in the credit and money supply in analytical forms.

Another important examination of the effects of Basel III regulations on credit supply is provided by macroeconomic models. Goodhart et al. (2012, 2013) integrate bank balance sheets into a general equilibrium model. Their model emphasizes the role of the balance sheet in introducing the regulations and presents the dynamics of the balance sheet quantities. They reveal that the CAR or LCR reduces risky illiquid mortgage loans and that the LCR also increases riskless liquid short-term loans; the LCR may cause massive deleveraging of banks. Macroeconomic Assessment Group (2010a,b) examines the impact of phasing in the CAR, LCR, and the NSFR. Implementing the regulations results

[4]In addition, a few banking models explicitly incorporate the balance sheet. For example, Cecchetti and Kashyap (2018) explain the interactions between the capital and liquidity regulations while Danielsson et al. (2011) discuss the risk-taking of banks.

in decreasing loan quantities and increasing loan spreads. Angelini et al. (2015); Basel Committee on Banking Supervision (2010) select several typical macroeconomic models, most being dynamic stochastic general equilibrium (DSGE) models, to examine the long-term costs and benefits of the implementation of the CAR and the NSFR. These two papers find that the regulations affect loan spreads rather than loan quantities. Covas and Driscoll (2014) find that when banks are subject to the CAR, the introduction of the LCR decreases loans and increases riskless securities, leading to a decline in output. Boissay and Collard (2016) shed light on the interactions between the capital regulations (the CAR and leverage ratio) and liquidity regulations. As their paper argues, regulations may reduce the credit supply but they can improve the allocation of credit.

To examine regulations via macroeconomic models, it is necessary to simplify the regulations, especially liquidity regulations. For example, such models abstract from switches within different LCR regimes according to the cash flow positions of banks. In addition, macroeconomic models need to consider the role of banks' balance sheets and creation of credit and money (Jakab and Kumhof, 2015). My model focuses on banks expanding and contracting their balance sheets. Then, the regulatory constraints on such bank behavior limit the supply of credit and money. Such a description of banks may provide a foundation for integrating bank balance sheets and then the creation of credit and money into macroeconomic models.

A vast amount of empirical literature examines the impact of the CAR introduced under Basel I and II on the credit supply. For a survey of this literature, see VanHoose (2006). Most of the relevant literature reports that the regulations reduce the credit supply. In recent years, empirical papers have focused on the effects of the more stringent capital and new liquidity regulations introduced under Basel III. Similar to the CAR under Basel I and II, the Basel III CAR leads to declines in the credit supply (Gropp et al., 2019), increases in loan spreads (Slovik and Cournède, 2011), or declines in the credit supply together with increases in loan rates (Cosimano and Hakura, 2011).

Relative to the examinations of the CAR, efforts to explore the impact of the LCR and the NSFR are few mainly due to data limitations. King (2013) finds that when banks are subject to the NSFR, banks do not prefer to reduce loans with high returns but have to experience a decline in net interest margins. Furthermore, Naceur et al. (2018) show that the NSFR has a positive effect on lending. Other efforts investigate the effects of the LCR and NSFR on bank failures (Hong et al., 2014), the LCR on the amplification of sovereign risk (Buschmann and Schmaltz, 2017), and the LCR on term deposit facilities (a monetary policy tool that drains reserves from the banking system) (Rezende et al., 2021). In addition, several important insights into the LCR are derived from discussing two other similar liquidity regulations: the Dutch liquidity ratio (DLCR) introduced in 2003, and the UK individual liquidity guidance (ILG) introduced in 2010. Bonner and Eijffinger (2016) find that the DLCR does not significantly affect loan rates. Furthermore, as Bonner (2016) demonstrates, when considering both the DLCR and the CAR, banks intend to substitute government bonds for other bonds and reduce loans. As for the ILG, Banerjee and Mio (2018) show that it appears to have no significant impact on loan supply or rates.

My theoretical paper complements the empirical studies mentioned by showing the basic analytical expressions for the credit and money supply; such expressions are linked to loan and deposit rates and rules of the regulations.

This paper is organized as follows. Section 2 briefly describes the CAR, LCR, and the NSFR. Section 3 presents the model. The effects of interest payment shocks on credit and money creation under the CAR are shown in Section 4, under the LCR in Section 5, and under the NSFR in Section 6. Section 7 concludes the paper. The omitted derivations and a glossary of notations are located in the Appendix.

2. A brief description of bank regulations

In this section, I briefly describe the CAR, the LCR, and the NSFR.

2.1. Capital adequacy ratios

The CAR requires banks to hold sufficient capital to avoid bank failures caused by adverse shocks. Such shocks mainly include the reduction of the capital of banks, or namely, a threat to the solvency of banks such as a decline in security prices and defaults on credit.

The CAR requires banks to maintain a minimum ratio of capital to total risk-weighted assets. In the Basel III accord, bank capital is classified into three types according to quality: Common Equity Tier 1 capital, Additional Tier 1 capital, and Tier 2 capital. The sum of Common Equity Tier 1 and Additional Tier 1 capital is Tier 1 capital. The sum of Tier 1 and Tier 2 capital is Total capital. Total risk-weighted assets are calculated by summing the value of each asset multiplied by its risk weight.

Banks must achieve a ratio of Common Equity Tier 1 capital to total risk-weighted assets no lower than 4.5%, Tier 1 capital no lower than 6%, and Total capital no lower than 8%. Denote by *car* the required capital adequacy ratio. The CAR can be given by

$$\frac{Capital}{Total\ risk\text{-}weighted\ assets} \geq car. \tag{1}$$

2.2. Liquidity coverage ratios

It has been widely recognized that merely having adequate capital does not ensure the soundness of banks. In particular, the liquidity difficulties faced by banks during the 2008 financial crisis emphasize how crucial it is for banks to hold sufficient high-quality liquid assets to cover liquidity shortages. To address this issue, Basel III proposes two liquidity regulations: the LCR and the NSFR.

The LCR requires banks to maintain a sufficient stock of unencumbered high-quality liquid assets to cover the expected net cash outflows in a 30-calendar-day liquidity stress scenario. During these 30 days, regulators and supervisors are expected to take corrective and effective actions to address liquidity problems.

The unencumbered high-quality liquid assets are classified as Level 1 and

Level 2 according to their liquidity.[5] Level 1 assets with the highest liquidity include coins, banknotes, and central bank reserves. The Level 2 assets have lower liquidity than Level 1 assets. Level 2 assets include corporate debt securities, covered bonds, and residential mortgage-backed securities. The share of Level 2 assets is up to 40% after the required haircuts. Cash outflows are the sum of outstanding balances of liabilities and off-balance-sheet commitments to run off or be drawn down in the stress scenario, such as a deposit run-off or interest expenses. Cash inflows include contractual payments to be received by banks, such as principal payments and interest income on loans. The payments received should be multiplied by their inflow percentages. The cash inflows are capped at 75% of total outflows. Thus, net cash outflows for the subsequent 30 calendar days are given by

$$\begin{aligned}&\textit{Net cash outflows for the subsequent 30 calendar days}\\&= \textit{Cash outflows} - \min(\textit{Cash inflows}, 0.75 \times \textit{Cash outflows}).\end{aligned} \tag{2}$$

The LCR is based on the traditional "coverage ratio" liquidity management method. The LCR can be written as follows.

$$\frac{\textit{Unencumbered high-quality liquid assets}}{\textit{Net cash outflows for the subsequent 30 calendar days.}} \geq lcr, \tag{3}$$

where lcr is the required LCR ratio, which is 100% under Basel III.

2.3. Net stable funding ratios

The NSFR is another liquidity regulation for banks under Basel III to complement the LCR. It is designed to reduce maturity mismatches between assets and liabilities. The NSFR requires banks to have a stable funding profile over a one-year horizon and it is defined as the ratio of the quantity of ASF (available stable funding) to the quantity of RSF (required stable funding).

[5] Furthermore, Level 2 assets consist of Level 2A and 2B assets. According to the LCR rules, the liquidity of Level 2A assets is higher than that of Level 2B assets. For further details, see Basel Committee on Banking Supervision (2013)

The amount of ASF assesses the stability of funding sources of banks. The NSFR assigns an ASF factor to each of the liabilities or capital. The ASF factor depends on the tenor and propensity of withdrawing the funding. The ASF factors vary from 0% to 100%. The more reliable the funding source, the larger the ASF factor assigned to it. For example, the ASF factor for capital takes a value of one. Multiplying capital and liabilities by their ASF factors and summing all the weighted amounts yields the amount of the ASF. On the other hand, the amount of the RSF measures the liquidity of the assets and the off-balance-sheet exposures. The NSFR assigns an RSF factor to each of the assets. The RSF factor is based on the tenor and liquidity of the asset. The RSF factors also vary from 0% to 100%, with the higher the liquidity, the smaller the RSF factor. Similarly, the amount of the RSF is the sum of assets weighted by their RSF factors.

Finally, I express the NSFR as follows.

$$\frac{\textit{Total available stable funding}}{\textit{Total required stable funding}} \geq nsfr, \tag{4}$$

where *nsfr* denotes the required NSFR ratio, 100% under the Basel III accord.

3. The model

In this section, I describe the balance sheets of banks before and after interest payment shocks occur. Following this, I present the objective functions before and after interest payment shocks. Finally, each regulation described in Section 2 becomes the constraints on the bank balance sheets. By combining the objective functions and the regulatory constraints, I obtain the bank's maximization problems under the regulation.

3.1. Balance sheets and timeline

There are three dates $t = 0$, 1, and 2. Balance sheets and notations at date t are presented in Table 1.[6] The balance sheet quantities satisfy the balance

[6] The balance sheet presents the stock variables. The quantity of a stock variable at date t represents that of the variable *at the end of* the date t. By contrast, interest payments are

Table 1

Balance sheets of banks

Assets	Liabilities
Loans L_t	Deposits D_t
Securities S	
Required Reserves R	Equity E_t

sheet identity:

$$L_t + S + R = D_t + E_t. \tag{5}$$

Here, I focus on banks supplying loans and money. Securities and reserves are assumed to be constant.

Table 2

Timeline

Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
L_0	D_0	L_0	$D_0 - I + P$	L_2	D_2
S		S		S	
R	E	R	$E + I - P$	R	$E + I - P$
Date 0		Date 1		Date 2	

Table 2 illustrates the balance sheets in the three dates. On date 0, banks seek to maximize their profits. Bank equity E_0 is given by E. As shown by the balance sheet, banks earn interest on loans and securities. On the other hand, banks have to pay interest on deposits. Taking all the income and expense into account, I obtain the profit on date 0 as

$$\Pi_0 = i_L L_0 + i_S S - i_D D_0, \tag{6}$$

flow variables. The amount of a flow variable at date t represents that of the variable *during* the date t.

where the loan rate is i_L, the security rate is i_S, and the deposit rate is i_D. Rearranging the balance sheet identity in Eq. (5), I have

$$D_t = L_t + S + R - E_t. \tag{7}$$

Substituting Eq. (7) into Eq. (6), I obtain

$$\Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E. \tag{8}$$

Thus, banks choose loans to solve

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E, \tag{9}$$

subject to one of the CAR, LCR, and NSFR constraints at date 1.

At $t = 1$, loans and securities generate interest payments to banks, which increases their equity. Deposits cause interest payments from banks, which decreases their equity. Consider the two interest payments above as shocks to banks' equity. The changes in equity are given by interest payment shocks, which are defined below.

Definition 1. Interest payment shocks ΔE are defined as banks receiving interest on assets and paying interest on liabilities. Denote the interest receipt as I and the interest expenditure as P. The interest payment shocks ΔE can be formulated as

$$\Delta E = E_1 - E = I - P. \tag{10}$$

According to Definition 1, the interest payment shocks change equity to $E + I - P$ at date 1.

At date 2, banks adjust their loans to maximize their profits. Because $E_2 = E_1$, from Eq. (10), I have

$$\Delta E = E_2 - E = E_1 - E = I - P. \tag{11}$$

As Eq. (11) shows, the equity also equals $E + I - P$ at date 2. Based on the maximization problem at date 0 in Eq. (9), I have the bank's maximization problem at date 2 as

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + I - P), \tag{12}$$

subject to one of the regulatory constraints: the CAR, LCR, and NSFR constraints at date 2.

3.2. Bank regulations

In Section 2, I briefly describe the rules of the CAR, LCR, and NSFR. This section shows when banks maximize their profits, the regulations become the constraints of them. Now, I present the formula for each regulatory constraint.

Capital adequacy ratio. Let γ_L be the risk weight for loans and γ_S be that for securities. Then, the CAR in Eq. (1) can be written as

$$\frac{E_t}{\gamma_L L_t + \gamma_S S} \geq car. \tag{13}$$

Liquidity Coverage Ratio. First, according to the balance sheet shown by Table 1, reserves R and securities S compose the high-quality liquid assets $HQLA$. Let χ denote the haircut for securities. Thus, I have

$$HQLA = R + (1 - \chi)S. \tag{14}$$

Second, I show the expressions for cash inflows IF_t and cash outflows OF_t. The cash inflows are written as

$$IF_t = \kappa(i_L + \mu)L_t, \tag{15}$$

where κ is the inflow percentage, and μ is the fraction of loans repaid. On the other hand, the outflows are given by

$$OF_t = (i_D + \alpha)D_t, \tag{16}$$

where α is the run-off rate for deposits.

The LCR has two regulatory regimes associated with the expressions for the net cash outflows in Eq. (2). If $IF_t \geq 0.75 OF_t$ ($\kappa(i_L + \mu)L_t \geq 0.75(i_D + \alpha)D_t$), the net cash outflows $NCOF$ are

$$0.25(i_D + \alpha)D_t. \tag{17}$$

If $IF_t < 0.75OF_t$ $(\kappa(i_L + \mu)L_t < 0.75(i_D + \alpha)D_t)$, $NCOF$ become

$$(i_D + \alpha)D_t - \kappa(i_L + \mu)L_t. \tag{18}$$

Finally the expression for the LCR in Eq. (3) with $IF_t \geq 0.75OF_t$ is

$$\frac{R + (1 - \chi)S}{0.25(i_D + \alpha)D_t} \geq lcr; \tag{19}$$

and with $IF_t < 0.75OF_t$, the formula for the LCR becomes

$$\frac{R + (1 - \chi)S}{(i_D + \alpha)D_t - \kappa(i_L + \mu)L_t} \geq lcr. \tag{20}$$

Net Stable Funding Ratio. According to the rules of the NSFR, the ASF factor for equity takes a value of one. Considering the balance sheet of banks presented by Table 1, I write the expression for the NSFR in Eq. (4) as

$$\frac{\beta D_t + E_t}{\phi_L L_t + \phi_S S} \geq nsfr, \tag{21}$$

where β is the ASF factor for deposits, ϕ_L is the RSF factor for loans, and ϕ_S is the RSF factor for securities.

4. Credit creation under capital adequacy ratios

I compare the supply of credit after the shocks to that before the shocks. In what follows, I show the difference $L_2 - L_0$ when banks are subject to the CAR. Credit creation drives money creation. Thus the difference in the money supply before and after the shocks, $D_2 - D_0$, is also obtained.

To obtain $L_2 - L_0$ and $D_2 - D_0$, I discuss the bank's maximization problems at date 0 and date 2. The Lagrangians and first-order conditions are given in Appendix A.

At $t = 0$, from the objective function in Eq. (9) and the CAR constraint in Eq. (13), the bank's maximization problem is

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$car(\gamma_L L_0 + \gamma_S S) \leq E,$$

and the nonnegativity constraint $L_0 \geq 0$. From the first-order conditions and balance sheet identity in Eq. (5), I have L_0 and D_0 determined by

$$car(\gamma_L L_0 + \gamma_S S) = E, \tag{22}$$

$$L_0 + S + R = D_0 + E. \tag{23}$$

At $t = 1$, interest payment shocks ΔE occur. According to Definition 1, interest payment shocks consist of interest receipts on loans, $i_L L_0$, interest receipts on securities, $i_S S$, and interest expenditures on deposits, $i_D D_0$. To identify the effects of the interest payment shocks, I need to introduce dummy variables. A dummy variable takes a value of one if the interest payment shocks include the corresponding interest receipt or expenditure and zero otherwise. The dummy variable σ_L is associated with interest receipt on loans, σ_S with interest receipt on securities, and σ_D with interest expenditure on deposits.

The formula of interest payment shocks in Eq. (10) can be rewritten as

$$\Delta E = E_1 - E = I - P, \tag{24}$$

where

$$I = \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S, \tag{25}$$

$$P = \sigma_D \cdot i_D D_0. \tag{26}$$

At $t = 2$, in response to interest payment shocks, banks adjust the credit supply to again maximize their profits. The equity E_2 equals E_1. So substituting Eqs. (25) and (26) into the objective function in Eq. (12) and the CAR constraint in Eq. (13), I obtain the bank's problem at date 2 is to solve

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$car(\gamma_L L_2 + \gamma_S S) \leq E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0,$$

and the nonnegativity constraint $L_2 \geq 0$. Again, I use the first-order conditions and balance sheet identity in Eq. (5) to obtain the equations for determining

L_2 and D_2:

$$car(\gamma_L L_2 + \gamma_S S) = E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0, \tag{27}$$

$$L_2 + S + R = D_2 + E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0. \tag{28}$$

In summary, the system of equations to determine L_0, L_2, D_0, and D_2 is given in Eqs. (22), (23), (27) and (28). Solving these, I display the solutions in Appendix A. Here, I show $L_2 - L_0$ as follows:

$$\begin{aligned} L_2 - L_0 = \sigma_L \cdot \frac{1}{car \cdot \gamma_L} \cdot i_L L_0 + \sigma_S \cdot \frac{1}{car \cdot \gamma_L} \cdot i_S S \\ -\sigma_D \cdot \frac{1}{car \cdot \gamma_L} \cdot i_D D_0. \end{aligned} \tag{29}$$

From Eq. (29), $L_2 - L_0$ can further be expressed as the link between interest payment shocks and the changes in the credit supply, as summarized in Proposition 1.

Proposition 1. *When banks are subject to the CAR, the changes in the credit supply in response to the interest payment shocks* ΔE *are given by*

$$L_2 - L_0 = \frac{1}{car \cdot \gamma_L} \cdot \Delta E. \tag{30}$$

- *The credit supply is increasing in the equity.*
- *Interest payment shocks cause a multiplier effect on the credit supply. The multiplier is*

$$\frac{1}{car \cdot \gamma_L} \geq 1. \tag{31}$$

According to the Basel III rules, $car = 8\%$ and $\gamma_L \leq 1250\%$. In only a few extreme cases does the risk weight equal the maximum of 1250%. In general, there is $\gamma_L < 1250\%$. Thus, the multiplier is larger than one. Proposition 1 indicates that banks amplify the changes in equity resulting from the interest payment shocks under the CAR. The multiplier is decreasing in car or γ_L, either of which represents the stringency of the CAR. An increase in the stringency of the CAR reduces not only the supply of credit but also the multiplier effect on the credit supply. This finding supports that Basel III strengthens the CAR to avoid excessive credit expansion.

Additionally, I exhibit the changes in deposits $D_2 - D_0$:

$$D_2 - D_0 = \sigma_L(\frac{1}{car \cdot \gamma_L} - 1)i_L L_0 + \sigma_S(\frac{1}{car \cdot \gamma_S} - 1)i_S S$$
$$-\sigma_D(\frac{1}{car \cdot \gamma_L} - 1)i_D D_0. \tag{32}$$

Eq. (32) yields the relationship between the interest payment shocks and changes in the money supply:

$$D_2 - D_0 = (\frac{1}{car \cdot \gamma_L} - 1)\Delta E, \tag{33}$$

which also demonstrates a multiplier effect.

Finally, the constraints of $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$ yield the following condition:

$$(S + R - E)(car(\gamma_L - \frac{S}{S + R - E} \cdot \gamma_S) + \frac{E}{S + R - E}) > 0.$$

See Appendix A for details on the derivation of the condition.

5. Credit creation under liquidity coverage ratios

In this section, I examine the impact of the interest payment shocks on credit creation under the LCR. To do so, I adopted the same method as used in Section 4. The changes in the money supply, the effects on money creation, are also presented. The Lagrangians and first-order conditions are given in Appendix B.1 for Case HH, in Appendix B.2 for Case LL, in Appendix B.3 for Case LH, and in Appendix B.4 for Case HL.

The discussion of the LCR presents a more complex result. The reason for this is that the LCR has two different regimes which correspond to differing LCR constraints. One is given by Eq. (19) under the condition $IF_0 \geq 0.75 OF_0$, denoted State H; and the other is given by Eq. (20) under the condition $IF_0 < 0.75 OF_0$, denoted State L. Before or after the shocks, the bank is in either State H or State L. This leads to four combinations consisting of Case HH, Case LL,

Table 3

Combinations of the LCR regimes

Case	Date 0	Date 2
HH	$IF_0 \geq 0.75OF_0$	$IF_2 \geq 0.75OF_2$
LL	$IF_0 < 0.75OF_0$	$IF_2 < 0.75OF_2$
LH	$IF_0 < 0.75OF_0$	$IF_2 \geq 0.75OF_2$
HL	$IF_0 \geq 0.75OF_0$	$IF_2 < 0.75OF_2$

Case LH, and Case HL, illustrated in Table 3. In the following sections, I discuss each case individually.

5.1. Case HH

In Case HH, banks are subject to the LCR with $IF_0 \geq 0.75OF_0$ (State H) and $IF_2 \geq 0.75OF_2$ (State H). The constraints at date 0 and date 2 take the same form as in Eq. (19):

$$\frac{R + (1-\chi)S}{0.25(i_D + \alpha)D_t} \geq lcr \tag{34}$$

for $t = 0, 2$. At $t = 0$, using Eqs. (9) and (19) and substituting for D_0 from the balance sheet identity in Eq. (7), I have the bank's problem:

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$0.25lcr((i_D + \alpha)(L_0 + S + R - E)) \leq R + (1-\chi)S,$$

and the nonnegativity constraint $L_0 \geq 0$. The first-order conditions with the balance sheet identity in Eq. (5) yield

$$0.25lcr((i_D + \alpha)(L_0 + S + R - E)) = R + (1-\chi)S \tag{35}$$

and

$$L_0 + S + R = D_0 + E \tag{36}$$

to determine L_0 and D_0.

At $t = 1$, banks are hit by the interest payment shocks ΔE. As in the discussion of the CAR and the interest payment shocks are given by

$$\Delta E = E_1 - E = I - P, \tag{37}$$

where

$$I = \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S, \tag{38}$$

$$P = \sigma_D \cdot i_D D_0. \tag{39}$$

At date 2, I have $E_2 = E_1 = I - P$. Banks adjust the balance sheets to maximize their profits with E_2. Substitute Eqs. (38) and (39) into Eqs. (12) and (19), together with the balance sheet identity in Eq. (7), to obtain the maximization problem at $t = 2$:

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$\begin{aligned} &0.25lcr((i_D + \alpha)(L_2 + S + R - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0))) \\ &\le R + (1 - \chi)S, \end{aligned}$$

and the nonnegativity constraint $L_2 \geq 0$. The first-order conditions with the balance sheet identity in Eq. (5) yield the equations to determine L_2 and D_2:

$$\begin{aligned} &0.25lcr((i_D + \alpha)(L_2 + S + R - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0))) \\ &= R + (1 - \chi)S, \end{aligned} \tag{40}$$

$$L_2 + S + R = D_2 + E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0. \tag{41}$$

Finally, L_0, L_2, D_0, and D_2 are obtained by solving the system of equations given in Eqs. (35), (36), (40) and (41). The solutions are presented in Appendix B.1. The difference in loans is given by

$$L_2 - L_0 = \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0. \tag{42}$$

Eq. (42) yields Proposition 2.

Proposition 2. *When banks are subject to the LCR with $IF_0 \geq 0.75OF_0$ and $IF_2 \geq 0.75OF_2$, interest payment shocks lead to*

$$L_2 - L_0 = \Delta E. \tag{43}$$

- *The changes in the credit supply equal interest payment shocks.*
- *Interest payment shocks do not cause multiplier effects on the credit supply. The multiplier equals one.*

Proposition 2 shows a special case of banks responding to the interest payment shocks. This is tantamount to banks using profits to finance loans or intermediating funds from shareholders to borrowers.

Moreover, we can see no changes in the money supply because the deposits do not change:

$$D_2 - D_0 = 0. \tag{44}$$

In addition, I can prove that $IF_2 = 0.75OF_2$ if and only if $IF_0 = 0.75OF_0$ (see Appendix B.1). Therefore, Case HH only includes $IF_t > 0.75OF_t$ for $t \in \{0, 2\}$ or $IF_t = 0.75OF_t$ for $t \in \{0, 2\}$. In the following discussion, Case LH only includes $IF_0 < 0.75OF_0$ and $IF_2 > 0.75OF_2$, and Case HL only includes $IF_0 > 0.75OF_0$ and $IF_2 < 0.75OF_2$.

5.2. Case LL

Now, I turn to the case of LCR with $IF_0 < 0.75OF_0$ (State L) and $IF_2 < 0.75OF_2$ (State L). In this case, the forms of the constraints at $t = 0$ and $t = 2$ are the same, which are given by Eq. (20). At date 0, from Eqs. (9) and (20), the bank's maximization problem can be written as

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$lcr((i_D + \alpha)(L_0 + S + R - E) - \kappa(i_L + \mu)L_0) \leq R + (1 - \chi)S,$$

and the nonnegativity constraint $L_0 \geq 0$. Using the first-order conditions and balance sheet identity in Eq. (5), I have L_0 and D_0 determined by

$$lcr((i_D + \alpha)(L_0 + S + R - E) - \kappa(i_L + \mu)L_0) = R + (1 - \chi)S, \tag{45}$$

$$L_0 + S + R = D_0 + E. \tag{46}$$

At date 1, the interest payment shocks ΔE, given by Eqs. (37)-(39), take place.

At date 2, I obtain the bank's problem by substituting Eqs. (38) and (39) into Eqs. (12) and (20) and using the balance sheet identity in Eq. (7). This leads to the following problem:

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$\begin{aligned} &lcr((i_D + \alpha)(L_2 + S + R - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)) \\ &\quad - \kappa(i_L + \mu)L_2) \leq R + (1 - \chi)S, \end{aligned}$$

and the nonnegativity constraint $L_2 \geq 0$. The first-order conditions and balance sheet identity in Eq. (5) yield the following equations to determine L_2 and D_2:

$$\begin{aligned} R + (1 - \chi)S = lcr((i_D + \alpha)(L_2 + S + R \\ -(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)) - \kappa(i_L + \mu)L_2), \end{aligned} \tag{47}$$

$$L_2 + S + R = D_2 + E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0. \tag{48}$$

The solutions for L_0, L_2, D_0, and D_2 are given by the system of equations in Eqs. (45)-(48). The solutions are shown in Appendix B.2. The impact on the credit supply is given by the changes in loans:

$$\begin{aligned} L_2 - L_0 = \sigma_L \cdot \frac{i_D + \alpha}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_L L_0 + \sigma_S \cdot \frac{i_D + \alpha}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_S S \\ -\sigma_D \cdot \frac{i_D + \alpha}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_D D_0. \end{aligned} \tag{49}$$

From Eq. (49), I have Proposition 3.

Proposition 3. *When banks are subject to the LCR with* $IF_0 < 0.75OF_0$ *and* $IF_2 < 0.75OF_2$*, the changes can be linked to the shocks* ΔE *as follows:*

$$L_2 - L_0 = \frac{i_D + \alpha}{i_D + \alpha - \kappa(i_L + \mu)} \cdot \Delta E. \tag{50}$$

- *The credit supply rises if the equity increases.*
- *Interest payment shocks have a multiplier effect on the credit supply. The multiplier is*

$$\frac{i_D + \alpha}{i_D + \alpha - \kappa(i_L + \mu)} > 1. \tag{51}$$

Proposition 3 demonstrates how banks amplify the interest payment shocks. The multiplier is increasing in κ and decreasing in α. A fall in κ or a rise in α means increases in the stringency of the LCR. Such increases result in a smaller multiplier. Strengthening the LCR reduces the amplification of the interest payment shocks. Notably, the multiplier, or the degree of amplification, does not depend on the value of the required LCR.

To show further findings, I rearrange the multiplier in Proposition 3 as

$$\frac{1}{1 - \frac{\kappa(i_L+\mu)}{i_D+\alpha}}. \tag{52}$$

The above expression for the multiplier has the implication concerning the liquidity of banks. To see the implication behind Eq. (52), I define the derivative of cash inflows with respect to loans as the marginal inflow of loans and the derivative of cash outflows with respect to deposits as the marginal outflow of deposits. From Eqs. (15) and (16), I discern that the marginal inflow of loans is $\kappa(i_L+\mu)$, and the marginal outflow of deposits is $i_D+\alpha$. Thus, $\kappa(i_L+\mu)/(i_D+\alpha)$ is the ratio of the marginal inflow of loans to the marginal outflow of deposits. This ratio indicates the liquidity of banks. A higher $\kappa(i_L + \mu)/(i_D + \alpha)$ means a higher liquidity of banks. As Eq. (52) presents, the multiplier is increasing in the ratio of $\kappa(i_L + \mu)/(i_D + \alpha)$. An increase in the liquidity increases the value of the multiplier or the amplification of the shocks.

Next, I exhibit the changes in the money supply. The changes in deposits are given by

$$D_2 - D_0 = \sigma_L \cdot \frac{\kappa(i_L + \mu)}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_L L_0 + \sigma_S \cdot \frac{\kappa(i_L + \mu)}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_S S$$
$$-\sigma_D \cdot \frac{\kappa(i_L + \mu)}{i_D + \alpha - \kappa(i_L + \mu)} \cdot i_D D_0. \tag{53}$$

Rearrange Eq. (53) to obtain

$$D_2 - D_0 = \frac{\kappa(i_L + \mu)}{i_D + \alpha - \kappa(i_L + \mu)} \cdot \Delta E. \tag{54}$$

5.3. Case LH

Case LH is connected to the LCR with $IF_0 < 0.75 OF_0$ (State L) and $IF_2 > 0.75 OF_2$ (State H). In contrast to Case HH and Case LL, interest payment shocks change the regime of the LCR. Specifically, the constraint changes from Eq. (20) (State L) at date 0 to Eq. (19) (State H) on date 2.

On date 0, the bank's problem is the same as that in Section 5.2:

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$lcr((i_D + \alpha)(L_0 + S + R - E) - \kappa(i_L + \mu)L_0) \leq R + (1 - \chi)S,$$

and the nonnegativity constraint $L_0 \geq 0$.

On date 1, the interest payment shocks ΔE, given by Eqs. (37)-(39), take place.

Then, on date 2, the maximization problem takes the same form as that in Section 5.1:

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$0.25 lcr((i_D + \alpha)(L_2 + S + R - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)))$$
$$\leq R + (1 - \chi)S,$$

and the nonnegativity constraint $L_2 \geq 0$.

The conditions are obtained from the first-order conditions in Section 5.2 and Section 5.1. Then, the system of equations specified in Eqs. (40), (41),

(45) and (46) determines L_0, L_2, D_0, and D_2. The solutions are presented in Appendix B.3. Here, I present the changes in loans as

$$\begin{aligned} L_2 - L_0 = \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0 \\ -D_0 + \frac{4(R + (1-\chi)S)}{lcr(i_D + \alpha)}. \end{aligned} \tag{55}$$

More importantly, from Eq. (55), I show the link between the credit supply and the interest payment shocks.

Proposition 4. *Under the LCR with $IF_0 < 0.75OF_0$ and $IF_2 > 0.75OF_2$, the changes in the credit supply can be decomposed into interest payment shocks ΔE as*

$$L_2 - L_0 = \Delta E - D_0 + \frac{4(R + (1-\chi)S)}{lcr(i_D + \alpha)}. \tag{56}$$

- *The increase in the equity increases the credit supply.*
- *Interest payment shocks do not lead to multiplier effects on the credit supply. The shocks have a multiplier of exactly one.*

Proposition 4 presents that Eq. (56) is divided into two groups. One with ΔE which is caused by the shocks and the other without ΔE is caused by the liquidity condition switching from $IF_0 < 0.75OF_0$ to $IF_2 > 0.75OF_2$. The group without ΔE in Eq. (56) can be decomposed into R, S, and E, which I present in Eq. (B.28).

The changes in the money supply are determined by those in the deposits:

$$D_2 - D_0 = -D_0 + \frac{4(R + (1-\chi)S)}{lcr(i_D + \alpha)}. \tag{57}$$

Eq. (57) shows $D_2 - D_0$ has nothing to do with the interest payment shocks ΔE. This means that the changes in the money supply are independent of the size of the shocks. In fact, Eq. (57) is the same as the group without ΔE in Eq. (56); Eq. (57) can also be decomposed into R, S, and E, which I also show in Eq. (B.28).

5.4. Case HL

Case HL concerns the LCR with $IF_0 > 0.75OF_0$ (State H) and $IF_2 < 0.75OF_2$ (State L). As in Case LH, the constraints for Case HL at date 0 and date 2 are different. In contrast to Case LH, Case HL begins with the constraint in Eq. (19) and ends with that in Eq. (20).

At date 0, the bank's maximization problem is the same as that in Section 5.1:

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$0.25lcr((i_D + \alpha)(L_0 + S + R - E)) \leq R + (1 - \chi)S,$$

and the nonnegativity constraint $L_0 \geq 0$.

At date 1, banks are hit by interest payment shocks ΔE, determined by Eqs. (37)-(39).

Then, the cash flow position changes to $IF_2 < 0.75OF_2$; the constraint becomes Eq. (20). The bank's problem at date 2 is the same as in Section 5.2:

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$\begin{aligned}&lcr((i_D + \alpha)(L_2 + S + R - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)) \\ &\quad - \kappa(i_L + \mu)L_2) \leq R + (1 - \chi)S,\end{aligned}$$

and the nonnegativity constraint $L_2 \geq 0$.

Repeating the same steps as in Section 5.1 and Section 5.2 yields the system of equations in Eqs. (35), (36), (47) and (48) to determine L_0, L_2, D_0, and D_2. The solutions are shown in Appendix B.4. The changes in loans are given by

$$\begin{aligned}L_2 - L_0 = &-\sigma_L \cdot \frac{i_D + \alpha}{\kappa(i_L + \mu) - (i_D + \alpha)} \cdot i_L L_0 - \sigma_S \cdot \frac{i_D + \alpha}{\kappa(i_L + \mu) - (i_D + \alpha)} \cdot i_S S \\ &-\sigma_D \cdot \frac{i_D + \alpha}{\kappa(i_L + \mu) - (i_D + \alpha)} \cdot (-i_D D_0) \\ &+\frac{(i_D + \alpha)D_0 - \kappa(i_L + \mu)L_0}{\kappa(i_L + \mu) - (i_D + \alpha)} - \frac{R + (1 - \chi)S}{lcr(\kappa(i_L + \mu) - (i_D + \alpha))}. \qquad (58)\end{aligned}$$

Based on Eq. (58), I get Proposition 5.

Proposition 5. *When banks are subject to the LCR with $IF_0 > 0.75 OF_0$ and $IF_2 < 0.75 OF_2$, the changes in the credit supply are linked to the shocks ΔE as follows:*

$$L_2 - L_0 = -\frac{i_D + \alpha}{\kappa(i_L + \mu) - (i_D + \alpha)} \cdot \Delta E + \frac{(i_D + \alpha)D_0 - \kappa(i_L + \mu)L_0}{\kappa(i_L + \mu) - (i_D + \alpha)} - \frac{R + (1 - \chi)S}{lcr(\kappa(i_L + \mu) - (i_D + \alpha))}. \tag{59}$$

- *Increases in the equity decrease the credit supply.*
- *Interest payment shocks result in a multiplier effect on the credit supply. The multiplier is*

$$\frac{i_D + \alpha}{\kappa(i_L + \mu) - (i_D + \alpha)}. \tag{60}$$

Proposition 5 shows that the effects are opposite in sign to those in Cases HH, LL, and LH. The changes in the credit supply consist of two groups: one with ΔE is caused by the shocks and the other without ΔE results from the switch of the LCR regimes. An alternative expression for the group without ΔE in Eq. (59) decomposed into R, S, and E is given in Eq. (B.37). This proposition also presents how the values of the multiplier can be greater or less than one, given by

$$\begin{cases} > 1 & \text{if } \kappa(i_L + \mu) < 2(i_D + \alpha), \\ = 1 & \text{if } \kappa(i_L + \mu) = 2(i_D + \alpha), \\ < 1 & \text{if } \kappa(i_L + \mu) > 2(i_D + \alpha). \end{cases}$$

On the one hand, if $\kappa(i_L + \mu) < 2(i_D + \alpha)$, then changes in the credit supply are greater than the size of the shocks, and interest payment shocks are thus amplified. On the other hand, if $\kappa(i_L + \mu) > 2(i_D + \alpha)$, then changes in the credit supply are smaller than the size of the shocks, and interest payment shocks are contracted. The LCR helps absorb the shocks.

The multiplier is decreasing in κ and increasing in α. A fall in κ or a rise in α means that there is an increase in the stringency of the LCR. The stringency of the LCR increased by decreasing κ or increasing α leads to a larger multiplier. Strengthening the LCR either increases the amplification of the shocks if $\kappa(i_L+\mu) < 2(i_D+\alpha)$ or reduces the contraction of the shocks if $\kappa(i_L+\mu) > 2(i_D+\alpha)$. Note that the multiplier is independent of the value of the required LCR.

To derive more implications about the multiplier, I rearrange Eq. (60) as

$$\frac{1}{\frac{\kappa(i_L+\mu)}{i_D+\alpha}-1}. \tag{61}$$

This expression offers a link between the multiplier and the liquidity of banks. The link can be obtained by using the ratio of the marginal inflow of loans to the marginal outflow of deposits, $\kappa(i_L+\mu)/(i_D+\alpha)$, which is associated with the liquidity of banks. A rise in the ratio means an increase in liquidity. Ultimately, increasing liquidity or the ratio decreases the multiplier. This reduces the amplification of the shocks if $\kappa(i_L+\mu) < 2(i_D+\alpha)$ or increases the contraction of the shocks if $\kappa(i_L+\mu) > 2(i_D+\alpha)$.

The changes in deposits,

$$\begin{aligned} D_2 - D_0 = {} & -\sigma_L \cdot \frac{\kappa(i_L+\mu)}{\kappa(i_L+\mu)-(i_D+\alpha)} \cdot i_L L_0 - \sigma_S \cdot \frac{\kappa(i_L+\mu)}{\kappa(i_L+\mu)-(i_D+\alpha)} \cdot i_S S \\ & -\sigma_D \cdot \frac{\kappa(i_L+\mu)}{\kappa(i_L+\mu)-(i_D+\alpha)} \cdot (-i_D D_0) \\ & + \frac{(i_D+\alpha)D_0 - \kappa(i_L+\mu)L_0}{\kappa(i_L+\mu)-(i_D+\alpha)} - \frac{R+(1-\chi)S}{lcr(\kappa(i_L+\mu)-(i_D+\alpha))}, \end{aligned} \tag{62}$$

yield the expression for the changes in the money supply linked to the interest payment shocks ΔE as

$$\begin{aligned} D_2 - D_0 = {} & -\frac{\kappa(i_L+\mu)}{\kappa(i_L+\mu)-(i_D+\alpha)} \cdot \Delta E \\ & + \frac{(i_D+\alpha)D_0 - \kappa(i_L+\mu)L_0}{\kappa(i_L+\mu)-(i_D+\alpha)} - \frac{R+(1-\chi)S}{lcr(\kappa(i_L+\mu)-(i_D+\alpha))}. \end{aligned} \tag{63}$$

As the changes in the credit supply in Eq. (59), Eq. (63) can be divided into two groups: one with ΔE and the other without ΔE. Indeed, the group without ΔE in Eq. (63) is the same as that in Eq. (59); the expression for the group without ΔE in Eq. (63) decomposed into R, S, and E is also given in Eq. (B.37).

5.5. Conditions for the cases of the LCR

In this section, I show the conditions for the four cases in Table 3. They are derived from (i) the combinations of the conditions for the LCR regimes before and after the shocks and (ii) the conditions for loans and deposits greater than zero. Detailed derivations of the conditions can be found in Appendix B.1 for Case HH, in Appendix B.2 for Case LL, in Appendix B.3 for Case LH, and in Appendix B.4 for Case HL. The conditions are summarized in Table 4.

Table 4

Conditions for Cases HH, LL, LH, and HL

Case	Date 0	Date 2	Condition
HH[a]	$IF_0 \geq 0.75OF_0$	$IF_2 \geq 0.75OF_2$	$\kappa(i_L + \mu) \geq 0.75(i_D + \alpha)$
LL	$IF_0 < 0.75OF_0$	$IF_2 < 0.75OF_2$	$\kappa(i_L + \mu) < 0.75(i_D + \alpha)$
LH	$IF_0 < 0.75OF_0$	$IF_2 > 0.75OF_2$	$\kappa(i_L + \mu) > i_D + \alpha$ and $(R + S - E)(i_D + \alpha - \frac{(1-\chi)S+R}{lcr(R+S-E)}) > 0$
HL	$IF_0 > 0.75OF_0$	$IF_2 < 0.75OF_2$	$\kappa(i_L + \mu) > i_D + \alpha$ and $(R + S - E)(i_D + \alpha - \frac{(1+4(i_L-i_D))((1-\chi)S+R)}{lcr(R+S-E)}) > 0$

[a] There is $IF_2 = 0.75OF_2$ if and only if $IF_0 = 0.75OF_0$.

6. Credit creation under net stable funding ratios

Next, I examine the impact of interest payment shocks on credit creation when banks are subject to the NSFR. To do so, I discuss the bank's maximization problems subject to the NSFR constraints in Eq. (21) on dates 0 and 2. The solutions to these problems determine the changes in the credit supply. From the dynamics of the balance sheet, I also present the changes in the money supply, i.e., the effects on money creation. The Lagrangians and first-order conditions are given in Appendix C.

On date 0, based on the objective function in Eq. (9), the bank's maximization problem is

$$\max_{L_0} \Pi = (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E$$

subject to

$$nsfr(\phi_L L_0 + \phi_S S) \leq \beta(L_0 + S + R) + (1 - \beta)E,$$

and the nonnegativity constraint $L_0 \geq 0$. By the first-order conditions and balance sheet identity in Eq. (5), I have L_0 and D_0 determined by

$$nsfr(\phi_L L_0 + \phi_S S) = \beta D_0 + E, \tag{64}$$

$$L_0 + S + R = D_0 + E, \tag{65}$$

$$\tag{66}$$

At $t = 1$, the bank is hit by the interest payment shocks ΔE. As in the analyses of the CAR and LCR, the interest payment shocks ΔE are formulated as

$$\Delta E = E_1 - E = I - P, \tag{67}$$

where

$$I = \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S \tag{68}$$

$$P = \sigma_D \cdot i_D D_0. \tag{69}$$

At $t = 2$, there is $E_2 = E_1$. With the equity E_2, banks adjust the balance sheets to maximize their profits. Substitute the expressions for I and P into the objective function in Eq. (12); then use the balance sheet identity in Eq. (7) to obtain the bank's problem at date 2:

$$\max_{L_2} \Pi = (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)$$

subject to

$$nsfr(\phi_L L_2 + \phi_S S) \leq \beta(L_2 + S + R) + (1 - \beta)(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0),$$

and the nonnegativity constraint $L_2 \geq 0$. From the first-order conditions and balance sheet identity in Eq. (5), L_2 and D_2 are given by the following equations:

$$nsfr(\phi_L L_2 + \phi_S S) = \beta D_2 + E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0, \tag{70}$$

$$L_2 + S + R = D_2 + E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0. \tag{71}$$

In summary, the system of equations to determine L_0, L_2, D_0, and D_2 is given in Eqs. (64), (65), (70) and (71). The solutions are shown in Appendix

C. The changes in loans are given by

$$L_2 - L_0 = \sigma_L \cdot \frac{1-\beta}{nsfr \cdot \phi_L - \beta} \cdot i_L L_0 + \sigma_S \cdot \frac{1-\beta}{nsfr \cdot \phi_L - \beta} \cdot i_S S \\ -\sigma_D \cdot \frac{1-\beta}{nsfr \cdot \phi_L - \beta} \cdot i_D D_0. \tag{72}$$

From Eq. (72), I have Proposition 6.

Proposition 6. *When banks are subject to the NSFR, there are two different effects and they are opposite in sign.*

(i) Case 1: $nsfr \cdot \phi_L > \beta$. The changes in the credit supply can be decomposed into interest payment shocks as

$$L_2 - L_0 = \frac{1-\beta}{nsfr \cdot \phi_L - \beta} \cdot \Delta E. \tag{73}$$

- *Increases in the equity increase the credit supply.*
- *Interest payment shocks cause a multiplier effect on the credit supply. The multiplier is*

$$\frac{1-\beta}{nsfr \cdot \phi_L - \beta}. \tag{74}$$

(ii) Case 2: $nsfr \cdot \phi_L < \beta$. The changes in the credit supply can be decomposed into interest payment shocks as

$$L_2 - L_0 = -\frac{1-\beta}{\beta - nsfr \cdot \phi_L} \cdot \Delta E. \tag{75}$$

- *Increases in the equity decrease the credit supply.*
- *Interest payment shocks cause a multiplier effect on the credit supply. The multiplier is*

$$\frac{1-\beta}{\beta - nsfr \cdot \phi_L}. \tag{76}$$

Proposition 6 has significant implications as follows.

Case 1. The values of the multiplier are

$$\begin{cases} > 1 & \text{if } nsfr \cdot \phi_L < 1, \\ = 1 & \text{if } nsfr \cdot \phi_L = 1, \\ < 1 & \text{if } nsfr \cdot \phi_L > 1. \end{cases}$$

First, if $nsfr \cdot \phi_L < 1$, the multiplier in Eq. (74) is greater than one. Interest payment shocks are amplified. Furthermore, the multiplier is decreasing in $nsfr \cdot \phi_L$ and increasing in β. A rise in $nsfr \cdot \phi_L$ or a fall in β increases the stringency of the NSFR. Thus, a more stringent NSFR from increasing $nsfr \cdot \phi_L$ or decreasing β leads to a smaller multiplier. The amplification of the shocks is thus reduced. Second, if $nsfr \cdot \phi_L > 1$, the multiplier in Eq. (74) is less than one. Banks contract or absorb interest payment shocks. The multiplier is decreasing in $nsfr \cdot \phi_L$ or β. As a result, either strengthening the NSFR by increasing $nsfr \cdot \phi_L$ or loosening the NSFR by increasing β decreases the multiplier. As a result, such adjustments of the NSFR increase the contraction of the shocks.

Case 2. The values of the multiplier are

$$\begin{cases} > 1 & \text{if } nsfr \cdot \phi_L > 2\beta - 1, \\ = 1 & \text{if } nsfr \cdot \phi_L = 2\beta - 1, \\ < 1 & \text{if } nsfr \cdot \phi_L < 2\beta - 1. \end{cases}$$

First, if $nsfr \cdot \phi_L > 2\beta - 1$, the multiplier given by Eq. (76) is greater than one. Interest payment shocks are amplified. Furthermore, the multiplier is increasing in $nsfr \cdot \phi_L$ or decreasing in β. Thus, strengthening the NSFR by increasing $nsfr \cdot \phi_L$ or decreasing β results in a larger multiplier. The amplification effect is increased. Second, if $nsfr \cdot \phi_L < 2\beta - 1$, the multiplier is less than one. Banks contract, or absorb, the shocks. The multiplier is also increasing in $nsfr \cdot \phi_L$ or decreasing in β. Strengthening the NSFR by increasing $nsfr \cdot \phi_L$ or decreasing β reduces the contraction effect.

Another interpretation links the multipliers to the liquidity of banks. To understand this interpretation, it is helpful to discuss a special case in which *nsfr* takes the value of one, as required under Basel III. The condition for Case 1 becomes $\phi_L > \beta$. Rearranging Eq. (74), I obtain the multiplier in Case 1 as

$$\frac{1}{1 - \frac{1-\phi_L}{1-\beta}}. \tag{77}$$

Similarly, the condition for Case 2 becomes $\phi_L < \beta$. From Eq. (76), the multiplier in Case 2 becomes

$$\frac{1}{\frac{1-\phi_L}{1-\beta}-1}. \tag{78}$$

Both Eq. (77) and Eq. (78) depend on the ratio $(1-\phi_L)/(1-\beta)$. Consider the meanings of the ASF factor for deposits, β, and the RSF factor for loans, ϕ_L. The ASF factor reflects the stability of deposits and the RSF factor indicates the liquidity of loans. An increase in the stability of deposits raises β, and an increase in the liquidity of loans lowers ϕ_L. The ratio, $(1-\phi_L)/(1-\beta)$, measures the liquidity of banks. A higher $(1-\phi_L)/(1-\beta)$ resulting from a rise in the stability of deposits or the liquidity of loans suggests a more liquid bank. Using such a ratio, I have the following interpretation for the multipliers.

In Case 1, as Eq. (77) show, when the liquidity of banks measured by the ratio increases, the multiplier and thus the amplification increase. In Case 2, as Eq. (78) presents, when the liquidity measured by the ratio increases, the multiplier decreases. The amplification decreases if $\phi_L > 2\beta-1$; the contraction increases if $\phi_L < 2\beta-1$.

In addition, I have the changes in deposits:

$$\begin{aligned} D_2 - D_0 = \sigma_L \cdot \frac{1-nsfr\cdot\phi_L}{nsfr\cdot\phi_L-\beta}\cdot i_L L_0 + \sigma_S \cdot \frac{1-nsfr\cdot\phi_L}{nsfr\cdot\phi_L-\beta}\cdot i_S S \\ -\sigma_D \cdot \frac{1-nsfr\cdot\phi_L}{nsfr\cdot\phi_L-\beta}\cdot i_D D_0; \end{aligned} \tag{79}$$

therefore the changes in the money supply can be linked to interest payment shocks as

$$D_2 - D_0 = \frac{1-nsfr\cdot\phi_L}{nsfr\cdot\phi_L-\beta}\cdot \Delta E. \tag{80}$$

Finally, from the constraints of $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$, I obtain

$$\begin{aligned} &(S+R-E)(nsfr\cdot\phi_L-\beta)(\beta - \frac{S}{S+R-E}\cdot nsfr\cdot\phi_S + \frac{E}{S+R-E}) > 0, \\ &(S+R-E)(nsfr\cdot\phi_L-\beta)(nsfr\cdot\phi_S - \frac{S}{S+R-E}\cdot nsfr\cdot\phi_S + \frac{E}{S+R-E}) > 0. \end{aligned}$$

See Appendix C for the detailed derivation of the condition.

7. Conclusion

In this study. I have investigated how the changes in banks' equity resulting from interest payments affect their credit and money creation under the Basel III regulations. I discuss three Basel III regulations: the capital adequacy ratio (CAR), liquidity coverage ratio (LCR), and net stable funding ratio (NSFR). Each regulation forms a regulatory relationship between the balance sheet quantities. Interest receipt and expenditure are viewed as shocks that change bank equity, identified as interest payment shocks.

In accordance with such relationships, the interest payment shocks to the equity affect credit creation. My model allows for the analytical links between the interest payment shocks and the changes in the credit supply under each regulation to be observed. These links present two main findings on credit creation for each regulation. One is whether the interest payment shocks increase or decrease the credit supply and the other is that the interest payment shocks to the bank's equity cause multiplier effects on the credit supply, or the response of the credit supply can be written as the size of the shocks multiplied by the multipliers. If the multiplier is greater than one, interest payment shocks are amplified; if it is less than one, they are contracted. Such multiplier effects arise because (i) banks are able to expand or contract their balance sheets and (ii) the regulations limit such expansion and contraction.

Under the CAR, if the interest payment shocks increase the equity, the credit supply also rises. The CAR causes only one multiplier greater than one. The multiplier is then determined by the required CAR and risk weight for loans. On the other hand, under the LCR or NSFR, there are multiple cases. The increases in equity can either increase or decrease the credit supply. Such an effect of the liquidity regulations seems contrary to intuition. The LCR or NSFR has multiple multipliers that range from less than to greater than one. The multipliers related to the LCR depend on loan rates, deposit rates, and the parameters associated with the LCR. The multipliers related to the NSFR depend on the parameters associated with the NSFR. These amplifications and contractions may suggest some unintended consequences of the regulations.

The creation and destruction of credit are accompanied by the creation and destruction of money. Using the balance sheet identity, I also obtain the effects on money creation. Similar to the effects on credit creation, the effects on money creation are given by the multiplier effects of interest payment shocks on the money supply.

The results of this study offer important policy implications. First, the multipliers depend on the parameters introduced under the regulations. In particular, the links between the multipliers and the stringency of the regulations are shown. These findings indicate how the amplifications or contractions measured by the multipliers change when policymakers adjust the regulations. Second, the effects of interest payment shocks demonstrate how the liquidity of banks affects the credit supply under the LCR or NSFR. Third, my model sheds light on the banks' responses to the policy interventions influencing the interest income or expenses.

A few extensions of this framework that may inform future studies are offered as follows. First, the present version of the model ignores some factors that may also influence credit creation such as adjustment costs, balance sheet costs, and risk-taking. My model can incorporate these factors in such a way that they can be added to the objective function of banks by describing them as terms dependent on the balance sheet quantities. Second, this model can be applied to examine other shocks that change bank equity; such shocks include credit defaults and equity injections, caused, for example, by the Capital Purchase Program of the Troubled Asset Relief Program. Credit defaults reduce bank equity. Examining the impact of credit defaults on the credit supply demonstrates the effectiveness of bank regulations, especially in times of stress. The Capital Purchase Program injects equity into banks. Assessing the effect of the Capital Purchase Program presents the interactions between the policy interventions and bank regulations.

CRediT authorship contribution statement

Boyao Li: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Resources; Software; Validation; Writing - original draft; Writing - review & editing.

Declaration of Competing Interest

None.

Appendix

In the following sections, I exhibit the Lagrangians and the first-order conditions on dates 0 and 2.

I thus present the solutions for L_0 and D_0 under the CAR, LCR, or NSFR. I only display the expressions for L_0 and D_0. It is straightforward to obtain L_2 and D_2. I can obtain L_2 and D_2 by letting the dummy variables, σ_L, σ_S, and σ_D, take a value of one and adding $L_2 - L_0$ to L_0 and $D_2 - D_0$ to D_0. The changes in loans, $L_2 - L_0$, and deposits, $D_2 - D_0$, have been shown in Sections 4-6.

For each regulation, I also present the conditions for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$. In addition, for the LCR, I derive the cash flow conditions given in Table 4.

Appendix A. Capital adequacy ratio

First, I show the Lagrangians and first-order conditions at date 0 and date 2. Let λ_0^C be the Lagrangian multiplier for the date-0 CAR constraint. The Lagrangian at date 0 is

$$\begin{aligned}\mathcal{L}_0^C = {} & (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E \\ & + \lambda_0^C(E - car(\gamma_L L_0 + \gamma_S S)).\end{aligned}$$

The first-order conditions can be written as

$$0 = i_L - i_D - car \cdot \gamma_L \lambda_0^C, \tag{A.1}$$

$$0 = E - car(\gamma_L L_0 + \gamma_S S). \tag{A.2}$$

Similarly, the Lagrangian at date 2 can be expressed as

$$\begin{aligned}\mathcal{L}_2^C = &(i_L - i_D)L_2 + (i_S - i_D)S - i_D R \\ &+ i_D(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0) \\ &+ \lambda_2^C(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0 - car(\gamma_L L_2 + \gamma_S S)),\end{aligned}$$

where λ_2^C is the Lagrangian multiplier. I have the first-order conditions as

$$0 = i_L - i_D - car \cdot \gamma_L \lambda_0^C, \tag{A.3}$$

$$0 = E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0 - car(\gamma_L L_0 + \gamma_S S). \tag{A.4}$$

Second, I show the solutions for L_0 and D_0.[7] Loans and deposits at date 0 are

$$L_0 = \frac{E - car \cdot \gamma_S S}{car \cdot \gamma_L}, \tag{A.5}$$

$$D_0 = (1 - \frac{\gamma_S}{\gamma_L})S + R + (-1 + \frac{1}{car \cdot \gamma_L})E. \tag{A.6}$$

Third, I give the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$. Note that securities, S, reserves, R, and equity, E, are large and of the order of magnitude of 10^Q. On the contrary, the loan rate, i_L, security rate, i_S, and deposit rate, i_D, are small and of the order of magnitude of 10^{-j}. In practice, Q and j are greater than zero, and Q is far greater than j. From L_0, $L_2 - L_0$, D_0, and $D_2 - D_0$, I obtain L_2 and D_2, which consist of terms of the order of 10^Q and 10^{Q-j}. Retaining only the highest-order terms in L_2 and D_2, I obtain the same expressions as L_0 and D_0. Thus, I only need to consider the constraints for $L_0 > 0$ and $D_0 > 0$. From Eqs. (A.5) and (A.6), $L_0 > 0$ and $D_0 > 0$ yield

$$E - car \cdot \gamma_S S > 0 \tag{A.7}$$

[7] I do not consider the cases in which banks do not lend.

and

$$car \cdot \gamma_L(S+R-E) - car \cdot \gamma_S S + E > 0, \tag{A.8}$$

respectively. The CAR constraint in Eq. (13) implies Eq. (A.7) must hold. Finally, the condition for loans and deposits greater than zero is given by Eq. (A.8).

Appendix B. Liquidity coverage ratio

Appendix B.1. Case HH

First, I show the Lagrangians and first-order conditions at date 0 and date 2. Denote by λ_0^{HH} the Lagrangian multiplier at date 0. The Lagrangian of the problem at date 0 is

$$\begin{aligned}\mathcal{L}_0^{HH} &= (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E \\ &\quad + \lambda_0^{HH}(R + (1-\chi)S - 0.25lcr((i_D+\alpha)(L_0 + S + R - E))).\end{aligned}$$

I get the first-order conditions as

$$0 = i_L - i_D - 0.25lcr\lambda_0^{HH}(i_D + \alpha), \tag{B.1}$$

$$0 = R + (1-\chi)S - 0.25lcr((i_D+\alpha)(L_0 + S + R - E)). \tag{B.2}$$

The Lagrangian at date 2 is

$$\begin{aligned}\mathcal{L}_2^{HH} &= (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D E \\ &\quad + \lambda_2^{HH}(R + (1-\chi)S - 0.25lcr((i_D+\alpha)(L_2 + S + R \\ &\quad -(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)))),\end{aligned}$$

where λ_2^{HH} is the Lagrangian multiplier. The first-order conditions can be written as

$$0 = i_L - i_D - 0.25lcr\lambda_2^{HH}(i_D + \alpha), \tag{B.3}$$

$$0 = R + (1-\chi)S - 0.25lcr((i_D+\alpha)(L_2 + S + R \tag{B.4}$$

$$-(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0))). \tag{B.5}$$

Second, the solutions for loans and deposits at date 0 are

$$L_0 = -R - S + E + \frac{4(R + (1-\chi)S)}{lcr(i_D + \alpha)}, \tag{B.6}$$

$$D_0 = \frac{4(R + (1-\chi)S)}{lcr(i_D + \alpha)}. \tag{B.7}$$

Third, I divide the derivation of the condition for this case into two steps. The first step shows the condition for $IF_0 \geq 0.75OF_0$ and $IF_2 \geq 0.75OF_2$. The second step yields the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$.

Step 1: At date 0, the condition for $IF_0 \geq 0.75OF_0$ is rearranged as

$$IF_0 - 0.75OF_0 \geq 0.$$

Substitute IF_0 from Eq. (15) and OF_0 from Eq. (16) into the above inequality to obtain

$$\kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 \geq 0. \tag{B.8}$$

Using the solutions for L_0 in Eq. (B.6) and D_0 in Eq. (B.7), I can straightforwardly obtain the above condition. As in the CAR, I use approximations to the conditions related to the LCR. As the interest rates i_L, i_S, and i_D, the deposit run-off rate α and fraction of loans repaid μ are also of a small order of magnitude. Without loss of generality, I assume that α and μ are of the order of magnitude of 10^{-j}, the same as that of i_L, i_S, and i_D. In addition, $lcr \approx 1$ and $0 < \kappa \leq 1$ are of the order of 1. Then, the terms on the left-hand side of Eq. (B.8) are of the order of 10^Q and 10^{Q-j}. Retaining only the highest-order terms, I have

$$\frac{4\kappa(i_L + \mu)(R + (1-\chi)S)}{lcr(i_D + \alpha)} - \frac{3(R + (1-\chi)S)}{lcr} \geq 0.$$

This leads to

$$\kappa(i_L + \mu) \geq 0.75(i_D + \alpha). \tag{B.9}$$

Next, I turn to the condition for $IF_2 \geq 0.75OF_2$. It can be written as

$$IF_2 - 0.75OF_2 \geq 0.$$

Substituting Eqs. (15) and (16) into $IF_2 - 0.75OF_2 \geq 0$ yields

$$\kappa(i_L + \mu)L_2 - 0.75(i_D + \alpha)D_2 \geq 0.$$

The above inequality can be rewritten as

$$\kappa(i_L + \mu)(L_2 - L_0) - 0.75(i_D + \alpha)(D_2 - D_0) \\ + \kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 \geq 0.$$

Substituting for $L_2 - L_0$ from Eq. (42), $D_2 - D_0$ from Eq. (44), L_0 from Eq. (B.6), and D_0 from Eq. (B.7), I find the highest order of the terms on the second line is higher than that of those on the first line. Thus, retaining only the highest-order terms yields

$$\begin{aligned} IF_2 - 0.75OF_2 &= \kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 \\ &= \frac{4\kappa(i_L + \mu)(R + (1 - \chi)S)}{lcr(i_D + \alpha)} - \frac{3(R + (1 - \chi)S)}{lcr} \geq 0, \end{aligned} \quad \text{(B.10)}$$

which is the same as the condition for $IF_0 \geq 0.75OF_0$ in Eq. (B.9).

Step 2: I show the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$. It is obvious that $D_0 > 0$ and $D_2 > 0$ must hold. From Eq. (B.6), $L_0 > 0$ yields

$$\frac{lcr(i_D + \alpha)E + (4 - lcr(i_D + \alpha))R + (4(1 - \chi) - lcr(i_D + \alpha))S}{lcr(i_D + \alpha)} > 0. \quad \text{(B.11)}$$

According to the LCR rule, I have $\chi \leq 0.75$, which leads to $4(1 - \chi) \geq 1$. In general, there is $lcr(i_D + \alpha) \leq 1$; then, $4(1 - \chi) - lcr(i_D + \alpha) \geq 0$ and $4 - lcr(i_D + \alpha) > 0$. Thus, $L_0 > 0$ must hold. The terms in L_2 are of the order of 10^{Q+j}, 10^{Q}, and 10^{Q-j}. Retaining only the highest-order terms, I simplify L_2 to

$$\frac{4(R + (1 - \chi)S)}{lcr(i_D + \alpha)}, \quad \text{(B.12)}$$

which must be greater than zero.

Therefore, the condition for Case HH is Eq. (B.9) from Step 1:

$$\kappa(i_L + \mu) \geq 0.75(i_D + \alpha). \quad \text{(B.13)}$$

In addition, the condition for $IF_0 \geq 0.75OF_0$ and that for $IF_2 \geq 0.75OF_2$ are the same. Therefore, I have $IF_2 = 0.75OF_2$ if and only if $IF_0 = 0.75OF_0$.

Appendix B.2. Case LL

First, I show the Lagrangians and first-order conditions at date 0 and date 2. Denote λ_0^{LL} as the Lagrangian multiplier at date 0. I show the date-0 Lagrangian as

$$\begin{aligned}\mathcal{L}_0^{LL} &= (i_L - i_D)L_0 + (i_S - i_D)S - i_D R + i_D E + \lambda_0^{LL}(R + (1-\chi)S \\ &\quad - lcr((i_D + \alpha)(L_0 + S + R - E) - \kappa(i_L + \mu)L_0)).\end{aligned}$$

The first-order conditions are given by

$$0 = i_L - i_D - lcr\lambda(i_D + \alpha - \kappa(i_L + \mu)), \tag{B.14}$$

$$0 = R + (1-\chi)S - lcr((i_D + \alpha)(L_0 + S + R - E) - \kappa(i_L + \mu)L_0). \tag{B.15}$$

I write the date-2 Lagrangian as

$$\begin{aligned}\mathcal{L}_2^{LL} &= (i_L - i_D)L_2 + (i_S - i_D)S - i_D R + i_D E \\ &\quad + \lambda_2^{LL}(R + (1-\chi)S - lcr((i_D + \alpha)(L_2 + S + R \\ &\quad - (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)) - \kappa(i_L + \mu)L_2)),\end{aligned}$$

where λ_2^{LL} is the Lagrangian multiplier. The first-order conditions are given by

$$0 = i_L - i_D - lcr\lambda(i_D + \alpha - \kappa(i_L + \mu)), \tag{B.16}$$

$$0 = R + (1-\chi)S - lcr((i_D + \alpha)(L_2 + S + R \tag{B.17}$$

$$- (E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0)) - \kappa(i_L + \mu)L_2). \tag{B.18}$$

In this case, L_0 and D_0 are given by

$$L_0 = \frac{(1 - lcr(i_D + \alpha))R + (1 - \chi - lcr(i_D + \alpha))S + lcr(i_D + \alpha)E}{lcr(i_D + \alpha - \kappa(i_L + \mu))}, \tag{B.19}$$

$$D_0 = \frac{(1 - lcr \cdot \kappa(i_L + \mu))R + (1 - \chi - lcr \cdot \kappa(i_L + \mu))S + lcr \cdot \kappa(i_L + \mu)E}{lcr(i_D + \alpha - \kappa(i_L + \mu))}. \tag{B.20}$$

As in Case HH, I divide the derivation of the condition into two steps. The first step shows the condition for $IF_0 < 0.75OF_0$ and $IF_2 < 0.75OF_2$. The second step gives the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$.

Step 1: At date 0, the condition for $IF_0 < 0.75OF_0$ is rewritten as

$$IF_0 - 0.75OF_0 < 0.$$

Substitute for IF_0 from Eq. (15) and for OF_0 from Eq. (16) into the above inequality to obtain

$$\kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 < 0.$$

Plugging Eqs. (B.19) and (B.20) into the left-hand side, I have that the terms on the left-hand side are of the order of 10^Q and 10^{Q-j}. Retaining only the highest-order terms, I obtain

$$\frac{(\kappa(i_L + \mu) - 0.75(i_D + \alpha))(R + (1 - \chi)S)}{lcr(i_D + \alpha - \kappa(i_L + \mu))} < 0. \tag{B.21}$$

At date 2, again using Eqs. (15) and (16), I have

$$\begin{aligned} IF_2 - 0.75OF_2 &= \kappa(i_L + \mu)L_2 - 0.75(i_D + \alpha)D_2 \\ &= \kappa(i_L + \mu)(L_2 - L_0) - 0.75(i_D + \alpha)(D_2 - D_0) \\ &\quad + \kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 < 0. \end{aligned}$$

Substituting for $L_2 - L_0$ from Eq. (49) and $D_2 - D_0$ from Eq. (53) into the second line and substituting for L_0 from Eq. (B.19) and D_0 from Eq. (B.20) into the third line, we see that the highest order of the terms on the third line is higher than that of those on the second line. Retaining only the highest-order terms, I have

$$\begin{aligned} &\kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 \\ &\qquad = \frac{(\kappa(i_L + \mu) - 0.75(i_D + \alpha))(R + (1 - \chi)S)}{lcr(i_D + \alpha - \kappa(i_L + \mu))} < 0. \end{aligned} \tag{B.22}$$

Thus, both $IF_0 < 0.75OF_0$ and $IF_2 < 0.75OF_2$ yield the same condition given by Eq. (B.21).

Step 2: I show the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$. The terms in L_0 and D_0 are of the order of 10^{Q+j} and 10^Q. First, retaining only the highest-order terms, I simplify $L_0 > 0$ and $D_0 > 0$ to

$$\frac{R + (1-\chi)S}{lcr(i_D + \alpha - \kappa(i_L + \mu))} > 0,$$

which leads to

$$i_D + \alpha - \kappa(i_L + \mu) > 0. \tag{B.23}$$

Second, the terms in L_2 and D_2 are of the order of 10^{Q+j}, 10^{Q}, and 10^{Q-j}. Retaining only the terms of the order of 10^{Q+j}, I obtain $L_2 > 0$ and $D_2 > 0$ as

$$\frac{R + (1-\chi)S}{lcr(i_D + \alpha - \kappa(i_L + \mu))} > 0, \tag{B.24}$$

which is the same condition as that for $L_0 > 0$ and $D_0 > 0$ in Eq. (B.23).

Finally, combining the condition in Eq. (B.21) from Step 1 and the condition in Eq. (B.23) from Step 2 yields the condition for Case LL:

$$\kappa(i_L + \mu) < 0.75(i_D + \alpha). \tag{B.25}$$

Appendix B.3. Case LH

In Case LH, the solutions for L_0 and D_0 are

$$L_0 = \frac{(1 - lcr(i_D + \alpha))R + (1 - \chi - lcr(i_D + \alpha))S + lcr(i_D + \alpha)E}{lcr(i_D + \alpha - \kappa(i_L + \mu))}, \tag{B.26}$$

$$D_0 = \frac{(1 - lcr \cdot \kappa(i_L + \mu))R + (1 - \chi - lcr \cdot \kappa(i_L + \mu))S + lcr \cdot \kappa(i_L + \mu)E}{lcr(i_D + \alpha - \kappa(i_L + \mu))}. \tag{B.27}$$

The solutions at date 0 are the same as those in Case LL, given by Eqs. (B.19) and (B.20). Using Eqs. (B.26) and (B.27), I can rewrite the group without ΔE in Eq. (56), $-D_0 + (4(R + (1-\chi)S))/(lcr(i_D + \alpha))$, as

$$\begin{aligned} &\frac{1}{lcr(i_D + \alpha)(\kappa(i_L + \mu) - (i_D + \alpha))} \\ &\qquad \times [(4\kappa(i_L + \mu) - 3(i_D + \alpha) - lcr \cdot \kappa(i_D + \alpha)(i_L + \mu))R \\ &\qquad + ((1-\chi)(4\kappa(i_L + \mu) - 3(i_D + \alpha)) - lcr \cdot \kappa(i_D + \alpha)(i_L + \mu))S \\ &\qquad + lcr \cdot \kappa(i_D + \alpha)(i_L + \mu)E], \end{aligned} \tag{B.28}$$

which is decomposed into R, S, and E.

The derivation of the conditions is divided into two steps. The first step presents the condition for $IF_0 < 0.75OF_0$ and $IF_2 > 0.75OF_2$. The second gives the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$.

Step 1: At date 0, using Eqs. (15) and (16), I rearrange $IF_0 < 0.75OF_0$ as

$$\kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0 < 0.$$

Substituting Eqs. (B.26) and (B.27) into the left-hand side of the above inequality, I have that the terms on the left-hand side are of the order of 10^Q and 10^{Q-j}; retaining only the highest-order terms yields

$$\frac{(R + (1-\chi)S)(\kappa(i_L + \mu) - 0.75(i_D + \alpha))}{lcr(i_D + \alpha - \kappa(i_L + \mu))} < 0. \tag{B.29}$$

At date 2, again using Eqs. (15) and (16) yields

$$\begin{aligned} IF_2 - 0.75OF_2 &= \kappa(i_L + \mu)L_2 - 0.75(i_D + \alpha)D_2 \\ &= \kappa(i_L + \mu)(L_2 - L_0) - 0.75(i_D + \alpha)(D_2 - D_0) \\ &\quad + \kappa(i_L + \mu)L_0 - 0.75(i_D + \alpha)D_0. \end{aligned}$$

Substituting for $L_2 - L_0$ from Eq. (55) and $D_2 - D_0$ from Eq. (57) into the second line and substituting for L_0 from Eq. (B.26) and D_0 from Eq. (B.27) into the third line, I prove that the terms in $IF_2 - 0.75OF_2$ are of the order of 10^Q, 10^{Q-j}, and 10^{Q-2j}. Retaining only the highest-order terms leads $IF_2 - 0.75OF_2 > 0$ to

$$\frac{4(\kappa(i_L + \mu) - 0.75(i_D + \alpha))(R + (1-\chi)S)}{lcr(i_D + \alpha)} > 0,$$

which implies

$$\kappa(i_L + \mu) - 0.75(i_D + \alpha) > 0. \tag{B.30}$$

Combine Eqs. (B.29) and (B.30) to obtain the condition for $IF_0 < 0.75OF_0$ and $IF_2 > 0.75OF_2$:

$$\kappa(i_L + \mu) > i_D + \alpha. \tag{B.31}$$

Step 2: First, I show the condition for $L_0 > 0$ and $D_0 > 0$. From Eqs. (B.26) and (B.27), using $i_D + \alpha < \kappa(i_L + \mu)$, I have that $L_0 > 0$ leads to $D_0 > 0$.

Therefore, I only need to show the condition for $L_0 > 0$. Rearranging $L_0 > 0$ yields

$$\frac{lcr(i_D+\alpha)(R+S-E)-(R+(1-\chi)S)}{\kappa(i_L+\mu)-(i_D+\alpha)} > 0. \tag{B.32}$$

The terms in Eq. (B.32) are of the order of 10^{Q+j} and 10^{Q}. Since $\kappa(i_L+\mu) > i_D+\alpha$, the terms of the order of 10^{Q+j} are negative. Because $L_0 > 0$, the highest-order approximation cannot be applied to the above inequality: the terms of the order of both 10^{Q+j} and 10^{Q} should be considered. From Eq. (B.32) and $\kappa(i_L+\mu) > i_D+\alpha$, the numerator of Eq. (B.32) must be greater than zero. Rearranging the numerator, I obtain

$$(R+S-E)(i_D+\alpha-\frac{R+(1-\chi)S}{lcr(R+S-E)}) > 0. \tag{B.33}$$

Second, I turn to $L_2 > 0$ and $D_2 > 0$. It is clear that D_2 must be greater than zero. The terms in L_2 are of the order of 10^{Q+j}, 10^{Q}, and 10^{Q-j}. Retaining only the highest-order terms, I simplify L_2 as

$$\frac{4(R+(1-\chi)S)}{lcr(i_D+\alpha)}, \tag{B.34}$$

which must be greater than zero. I obtain that the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$ is given by Eq. (B.33).

In summary, combining Eqs. (B.31) and (B.33), I prove that the conditions for Case LH are

$$\kappa(i_L+\mu) > i_D+\alpha,$$
$$(R+S-E)(i_D+\alpha-\frac{R+(1-\chi)S}{lcr(R+S-E)}) > 0.$$

Appendix B.4. Case HL

In Case HL, L_0 and D_0 are as follows:

$$L_0 = -R-S+E+\frac{4(R+(1-\chi)S)}{lcr(i_D+\alpha)} \tag{B.35}$$

and

$$D_0 = \frac{4(R+(1-\chi)S)}{lcr(i_D+\alpha)}. \tag{B.36}$$

The solutions at date 0 are the same as those in Case HH given by Eqs. (B.6) and (B.7). Using Eqs. (B.35) and (B.36), I rewrite the group without ΔE in Eq. (59),

$$\frac{(i_D+\alpha)D_0-\kappa(i_L+\mu)L_0}{\kappa(i_L+\mu)-(i_D+\alpha)}-\frac{R+(1-\chi)S}{lcr(\kappa(i_L+\mu)-(i_D+\alpha))},$$

as

$$\begin{aligned}
&-\frac{1}{lcr(i_D+\alpha)(\kappa(i_L+\mu)-(i_D+\alpha))}\\
&\qquad\times[(4\kappa(i_L+\mu)-3(i_D+\alpha)-lcr\cdot\kappa(i_D+\alpha)(i_L+\mu))R\\
&\quad+((1-\chi)(4\kappa(i_L+\mu)-3(i_D+\alpha))-lcr\cdot\kappa(i_D+\alpha)(i_L+\mu))S\\
&\qquad\qquad+lcr\cdot\kappa(i_D+\alpha)(i_L+\mu)E]. \qquad \text{(B.37)}
\end{aligned}$$

Note that Eq. (B.37) in Case HL is opposite in sign to Eq. (B.28) in Case LH.

As in the above cases, the first step presents the condition for $IF_0 > 0.75OF_0$ and $IF_2 < 0.75OF_2$. The second provides the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$.

Step 1: At date 0, using the inflows in Eq. (15), outflows in Eq. (16), L_0 in Eq. (B.35), and D_0 in Eq. (B.36), I have that the terms in $IF_0 - 0.75OF_0 > 0$ are of the order of 10^Q and 10^{Q-j}. Then, retaining only the highest-order terms yields

$$\frac{(R+(1-\chi)S)(4\kappa(i_L+\mu)-3(i_D+\alpha))}{lcr(i_D+\alpha)}>0,$$

which implies

$$\kappa(i_L+\mu)>0.75(i_D+\alpha). \qquad \text{(B.38)}$$

At date 2, I also use Eqs. (15) and (16) to obtain

$$\begin{aligned}
IF_2-0.75OF_2&=\kappa(i_L+\mu)L_2-0.75(i_D+\alpha)D_2\\
&=\kappa(i_L+\mu)(L_2-L_0)-0.75(i_D+\alpha)(D_2-D_0)\\
&\quad+\kappa(i_L+\mu)L_0-0.75(i_D+\alpha)D_0.
\end{aligned}$$

Substituting for $L_2 - L_0$ from Eq. (58) and $D_2 - D_0$ from Eq. (62) into the second line and substituting for L_0 from Eq. (B.35) and D_0 from Eq. (B.36) into the third line, I obtain that the terms in $IF_2 - 0.75OF_2$ are of the order of 10^Q, 10^{Q-j}, and 10^{Q-2j}. Retaining only the highest-order terms, I simplify $IF_2 - 0.75OF_2 < 0$ as

$$\frac{(R+(1-\chi)S)(\kappa(i_L+\mu)-0.75(i_D+\alpha))}{i_D+\alpha-\kappa(i_L+\mu)} < 0. \tag{B.39}$$

Together with Eq. (B.38), Eq. (B.39) reduces to

$$\kappa(i_L+\mu) > i_D+\alpha. \tag{B.40}$$

Eq. (B.40) is the condition for $IF_0 > 0.75OF_0$ and $IF_2 < 0.75OF_2$.

Step 2: First, I derive the condition for $L_0 > 0$ and $D_0 > 0$. From Eq. (B.36), it is obvious that $D_0 > 0$. From Eq. (B.35), $L_0 > 0$ can be rewritten as

$$\frac{lcr(i_D+\alpha)E+(4-lcr(i_D+\alpha))R+(4(1-\chi)-lcr(i_D+\alpha))S}{lcr(i_D+\alpha)} > 0.$$

The LCR rule says that $\chi \leq 0.75$; thus, $4(1-\chi) \geq 1$. In general, there is $lcr(i_D+\alpha) \leq 1$. Therefore, $4(1-\chi)-lcr(i_D+\alpha) \geq 0$ and $4-lcr(i_D+\alpha) > 0$. These imply that $L_0 > 0$ must hold. Turning to $L_2 > 0$ and $D_2 > 0$, the terms in L_2 and D_2 are of the order of 10^{Q+j}, 10^Q, and 10^{Q-j}. Their highest-order terms are negative. Because $L_2 > 0$ and $D_2 > 0$, the terms of the order of both 10^{Q+j} and 10^Q need to be considered. Thus, L_2 is approximated by

$$\frac{1}{lcr(\kappa(i_L+\mu)-(i_D+\alpha))} \times (R+S-E)(i_D+\alpha-\frac{(1+4(i_L-i_D))(R+(1-\chi)S)}{lcr(R+S-E)}).$$

Because of $\kappa(i_L+\mu) > i_D+\alpha$, $L_2 > 0$ simplifies to

$$(R+S-E)(i_D+\alpha-\frac{(1+4(i_L-i_D))(R+(1-\chi)S)}{lcr(R+S-E)}) > 0 \tag{B.41}$$

Similarly, D_2 is approximated by

$$\frac{1}{lcr(\kappa(i_L+\mu)-(i_D+\alpha))} \times (R+S-E)(i_D+\alpha-\frac{(\frac{i_D+\alpha}{\kappa(i_L+\mu)}+4(i_L-i_D))(R+(1-\chi)S)}{lcr(R+S-E)}).$$

Because of $\kappa(i_L+\mu) > i_D+\alpha$, $D_2 > 0$ simplifies to

$$(R+S-E)(i_D+\alpha-\frac{(\frac{i_D+\alpha}{\kappa(i_L+\mu)}+4(i_L-i_D))(R+(1-\chi)S)}{lcr(R+S-E)})>0. \quad \text{(B.42)}$$

Since $(i_D+\alpha)/(\kappa(i_L+\mu)) < 1$, the inequality in Eq. (B.41) implies the inequality in Eq. (B.42). Thus, the condition for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$ is given by Eq. (B.41)

To summarize, combining Eq. (B.40) from Step 1 and Eq. (B.41) from Step 2, I prove that the conditions for Case HL are

$$\begin{aligned} & i_D+\alpha < \kappa(i_L+\mu), \\ & (R+S-E)(i_D+\alpha-\frac{(1+4(i_L-i_D))(R+(1-\chi)S)}{lcr(R+S-E)})>0. \end{aligned}$$

Appendix C. Net stable funding ratio

First, I show the Lagrangians and first-order conditions at date 0 and date 2. The date-0 Lagrangian can be written as

$$\begin{aligned} \mathcal{L}_0^N = & (i_L-i_D)L_0+(i_S-i_D)S-i_DR+i_DE \\ & +\lambda_0^N(\beta(L_0+S+R)+(1-\beta)E-nsfr(\phi_LL_0+\phi_SS)), \end{aligned}$$

where λ_0^N is the Lagrangian multiplier. I get the first-order conditions as

$$0=i_L-i_D+\lambda(\beta-nsfr\phi_L), \quad \text{(C.1)}$$

$$0=\beta(L_0+S+R)+(1-\beta)E-nsfr(\phi_LL_0+\phi_SS). \quad \text{(C.2)}$$

Denote by λ_2^N the Lagrangian multiplier at date 2. I show the date-2 Lagrangian as

$$\begin{aligned} \mathcal{L}_2^N = & (i_L-i_D)L_2+(i_S-i_D)S-i_DR+i_DE \\ & +\lambda_2^N(\beta(L_2+S+R) \\ & +(1-\beta)(E+\sigma_L\cdot i_LL_0+\sigma_S\cdot i_SS-\sigma_D\cdot i_DD_0) \\ & -nsfr(\phi_LL_2+\phi_SS)). \end{aligned}$$

The first-order conditions are given by

$$0 = i_L - i_D + \lambda(\beta - nsfr\phi_L), \tag{C.3}$$

$$0 = (\beta(L_2 + S + R) + (1-\beta)(E + \sigma_L \cdot i_L L_0 + \sigma_S \cdot i_S S - \sigma_D \cdot i_D D_0) \tag{C.4}$$

$$-nsfr(\phi_L L_2 + \phi_S S)). \tag{C.5}$$

Second, the solutions for loans and deposits at date 0 are given by

$$L_0 = \frac{(\beta - nsfr \cdot \phi_S)S + \beta R + (1-\beta)E}{nsfr \cdot \phi_L - \beta}, \tag{C.6}$$

$$D_0 = \frac{nsfr(\phi_L - \phi_S)S + nsfr \cdot \phi_L R + (1 - nsfr \cdot \phi_L)E}{nsfr \cdot \phi_L - \beta}. \tag{C.7}$$

Third, I derive the conditions for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$. Rearranging L_0 in Eq. (C.6), I obtain the condition for $L_0 > 0$ as

$$(S+R-E)(nsfr \cdot \phi_L - \beta)(\beta - \frac{S}{S+R-E} \cdot nsfr \cdot \phi_S + \frac{E}{S+R-E}) > 0. \tag{C.8}$$

Similarly, I rearrange D_0 in Eq. (C.7) to show the condition for $D_0 > 0$ as

$$(S+R-E)(nsfr \cdot \phi_L - \beta)(nsfr \cdot \phi_S - \frac{S}{S+R-E} \cdot nsfr \cdot \phi_S + \frac{E}{S+R-E}) > 0. \tag{C.9}$$

Then, the terms in L_2 and D_2 are of the order of 10^Q and 10^{Q-j}. Retaining only the highest-order terms, I reduce L_2 and D_2 to L_0 and D_0, respectively. Therefore the conditions for $L_2 > 0$ and $D_2 > 0$ are the same as those for $L_0 > 0$ and $D_0 > 0$. In summary, the conditions for $L_0 > 0$, $D_0 > 0$, $L_2 > 0$, and $D_2 > 0$ are given by Eqs. (C.8) and (C.9).

Appendix D. Table of notations

Variable or parameter	Description
Panel A: Balance sheets of banks	
L	Loans
S	Securities

(continued on next page)

Variable or parameter	Description
R	Reserves
D	Deposits
E	Equity
Π	Profits
Panel B: Interest rates	
i_L	Loan rates
i_S	Security rates
i_D	Deposit rates
Panel C: Shocks	
I	Interest receipt
P	interest expenditure
Panel D: Dummy variables	
σ_L	Dummy variable for interest receipt on loans
σ_S	Dummy variable for interest receipt on securities
σ_D	Dummy variable for interest expenditure on deposits
Panel E: Regulations	
car	Required capital adequacy ratio
γ_L	Risk weight for loans
γ_S	Risk weight for securities
lcr	Required liquidity coverage ratio
$HQLA$	High-quality liquid assets
χ	Haircut for securities
$NCOF$	Net cash outflows
OF	Cash outflows
α	Run-off rate for deposits
IF	Cash inflows

(continued on next page)

Variable or parameter	Description
μ	Fraction of loans repaid
κ	Inflow rate for repayments
$nsfr$	Required net stable funding ratio
β	Available stable funding (ASF) factor for deposits
ϕ_L	Required stable funding (RSF) factor for loans
ϕ_S	Required stable funding (RSF) factor for securities

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