The Effect of Liquidity Regulation on U.S. Bank Risk-Taking: Evidence from Non-Performing Loans and CDS Spreads*

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Abstract

This paper illustrates channels by which regulations that require banks to hold liquid assets can either increase or decrease a bank's incentive to take risk with its remaining ineligible assets. A greater capacity to respond to liquidity stress increases the potential profits a bank would put at stake by making risky investments, but it also mitigates the illiquidity disadvantages of holding risky assets. We then empirically estimate the effect of two liquidity regulations on bank risk-taking as measured by the ratio of non-performing loans to total loans and credit default swap (CDS) spreads. Using a regression discontinuity design, we do not find evidence that reserve requirements significantly affected non-performing loans ratios. Using a difference-in-differences specification, we also do not find evidence that the liquidity coverage ratio significantly affected non-performing loans ratios or CDS spreads.

Keywords: liquidity regulation, bank risk, reserve requirements, liquidity coverage ratio, COVID-19, global financial crisis, CDS

JEL Classification: G21, G28

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1 Introduction

The liquidity stress observed during the 2008 financial crisis has led to increased attention on liquidity regulations. A prominent recent example is the liquidity coverage ratio (LCR), which has been effective in the US since January 2015. The LCR requires a subset of banks to hold a certain percentage of high quality liquid assets, such as cash and Treasury securities, against their 30-day net cash outflows. A notable historical precedent is the reserve requirement (RR), which existed in the US from the 1800s until 2020. The RR is similar to the LCR in that it required banks to hold a certain percentage of reserves, consisting of cash and deposits with the central bank, relative to their net transaction accounts, consisting of demand deposits and other liquid liabilities. Both of these liquidity regulations have been associated with increased holdings of liquid assets (see Figure 1).[1] How does increasing bank liquidity in turn affect financial stability? Recent studies have provided evidence that liquidity regulations are associated with fewer banks failures (Curfman and Kandrac (2018)) and reduced fire-sale risk (Roberts, Sarkar and Shachar (2018)). However, less is known about how liquidity regulations affect the incentive for banks to take risk with their remaining ineligible assets. Understanding the interactions between liquidity risk and credit risk is important for assessing the total effect of liquidity regulations on financial stability.

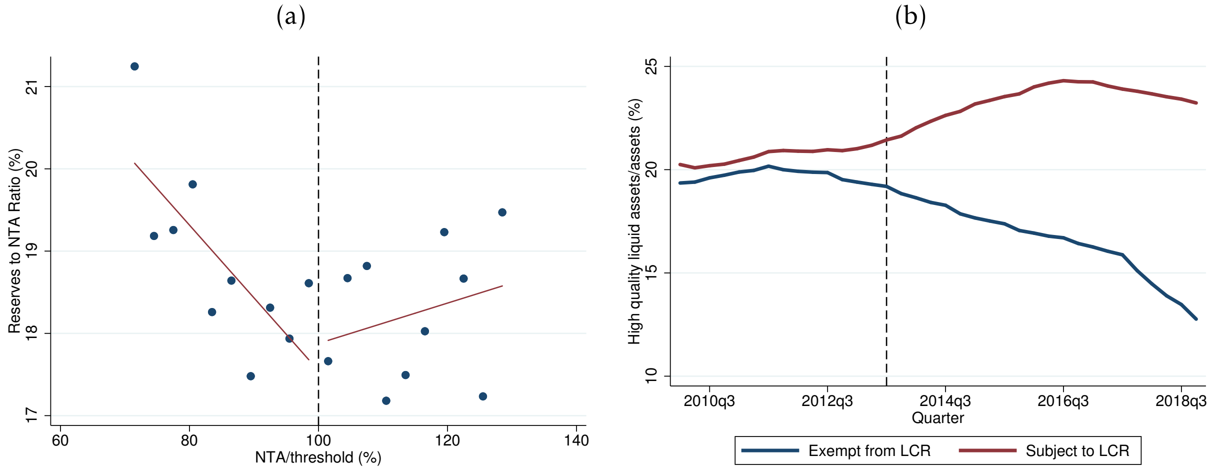
This paper introduces a model to illustrate channels by which regulations that require banks to hold liquid assets can either increase or decrease the incentive for banks to take risk with their remaining assets. In the model, a risk neutral bank acquires funding from depositors, maintains a required fraction of liquid assets, such as cash, and chooses the riskiness of its remaining long-term assets, such as loans.[2] Before the long-term assets mature, the bank may experience liquidity stress, which means that a fraction of its depositors withdraw their investment. The bank can respond to liquidity stress by either paying out of its liquid asset stock or, if necessary, selling its long-term assets in debt market to generate funds. On the one hand, limited liability and deposit insurance create an incentive for the bank to invest in risky long-term assets in order to maximize the option value of its net return.[3] On the other hand, risky assets sell at a lower price in the debt

[1] Figure 1(a) shows that banks hold more reserves when they are subject to higher marginal RR rates, and Figure 1(b) shows that bank holding companies (BHCs) that were subject to the LCR increased holdings of high quality liquid assets after the proposal of the LCR compared to BHCs that were exempt from the LCR.

[2] Liquid assets in the model can be interpreted more broadly to include reserves and certain types of securities, similar to Berger and Bouwman (2009). Both the LCR and the RR require banks to hold a sufficient stock of liquid assets, although they assign different weights to the various types of liquid assets and have a different method of computing the liabilities that these assets must be held against. See Section 4.1 and 5.1 for more details about the policies.

[3] Risky assets in the model can be interpreted, for example, as loans with a relatively high probability of default.

Figure 1: The effect of liquidity regulations on liquid asset holdings. Figure (a) presents a binned scatterplot relating the percentage of reserves to net transaction accounts to the percentage of net transaction accounts to a threshold at which marginal the reserve requirement rate exhibited a discontinuous jump. The figure also presents predicted values from estimating a linear regression for the subsamples on either side of the threshold. This figure uses Call Reports data from 1993Q1 to 2018Q4 for observations exhibiting a less than 30% deviation of net transaction accounts relative to the threshold. See Section 4 for more details. Figure (b) shows the mean ratio of high quality assets to liquid assets for a balanced sample of bank holding companies (BHCs), split between BHCs that were required to satisfy the liquidity coverage ratio (LCR) and those that were exempt from the LCR. The series have been smoothed using a moving average to reduce seasonal fluctuations. The dashed line indicates the proposal date for the LCR at approximately 2013Q3. The figure uses FR Y-9C data from 2010Q1 to 2018Q4. See Section 5 for more details.



market, which makes them less suitable for coping with liquidity stress. This trade-off determines whether the bank invests in risky or safe long-term assets.

The model illustrates that the effect of tightening liquidity requirements on the bank's incentive to invest in risky long-term assets qualitatively depends on its capacity to respond to liquidity stress. The bank has a low capacity to respond to liquidity stress if it owns few liquid assets and can only sell its long-term assets at a low price. In that case, liquidity stress can cause the bank to default. The bank can reduce the probability of default due to liquidity stress by investing in safe long-term assets, because they can be liquidated at a higher price in the debt market compared to risky assets. Tightening liquidity requirements improves the bank's profitability in states where it faces liquidity stress and but does not default. It therefore increases the profitability of safe assets relative to risky assets in states where the bank faces liquidity stress, which in turn increases the incentive to invest in safe assets ex-ante.

By contrast, the bank has a high capacity to respond to liquidity stress if it has a large stock of liquid assets or if the price of long-term debt is high. In that case, the bank can adequately respond to liquidity stress without defaulting, even if it invests in risky long-term assets. Tightening liquidity requirements decreases the extent to which the bank needs to sell its long-term assets in the debt market to respond to liquidity stress. This in turn mitigates the relative disadvantage of investing in risky assets, which is their lower price in the debt market. Hence, tightening liquidity requirements increases the incentive to invest in risky assets.

The result from the model that liquidity regulations can either increase or decrease the incentive to take risk motivates an empirical analysis to determine whether either effect dominates in practice. We first focus on a sharply identified setting in the context of the RR. In recent decades, the RR has primarily been used in the implementation of monetary policy (Feinman (1993)). However, the RR can also be understood as a liquidity regulation with a similar form as the LCR since both policies require banks to hold liquid assets against their liquid liabilities. Using quarterly Call Reports data, we exploit a discontinuous jump in marginal RR rates at a threshold in the volume of net transaction accounts. Implementing a regression kink design comparing banks that are marginally on either side of this threshold, we find that RR rates were associated with increased holdings of reserves but were not associated with changes in the ratio of non-performing loans to total loans, a measure of the riskiness of a bank's loan portfolio.

We also estimate the effects of the LCR using a difference-in-differences specification. Specifically, we exploit the fact that the LCR only applies to a subset of bank holding companies (BHCs) based on their size and foreign exposures. Using data from quarterly FR Y-9C filings by BHCs, we find that the proposal of the LCR in 2013 was associated with increased holdings of high quality liquid assets but was not associated with changes in non-performing loans ratios. We also do not find that the LCR was significantly associated with changes in jumps of credit default swap (CDS) spreads during the COVID-19 crisis compared to the global financial crisis, which suggests a limited effect of the LCR on overall bank risk during crises.

2 Literature Review

This paper addresses prior work that examines two important causes of bank failures. First, the liquidity risk associated with banks' maturity transformation role makes them vulnerable to runs (Diamond and Dybvig (1983)). Second, banks can also fail due to the credit risk associated with their investments. In particular, banks may have an incentive to take excessive risk or "gamble for resurrection" because the equityholders reap the rewards if it pays off while creditors or insurers absorb the losses if it fails (Hellmann, Murdock and Stiglitz (2000)). A bank's incentive to take risk is inversely related to its "charter value" or expected profits stream (Keeley (1990)). This paper combines these strands of the literature by illustrating how regulations that mitigate a bank's liquidity risk can increase the potential profits it could lose by investing the illiquid portion of its portfolio in risky assets.[4]

This paper is also related to the literature on financial crises. In this literature, crises are usually explained as being caused by either panics or weak fundamentals (Goldstein (2012)). The basic idea underlying this literature is that decision-makers transmit shocks by changing their exposure to risks. This literature is vast. For example, among others, bank runs associated with deteriorations in fundamentals are analyzed in Jacklin and Bhattacharya (1988) and Allen and Gale (1998), while self-fulfilling crises caused by panics among bank depositors are considered in Bryant (1980), Diamond and Dybvig (1983), and Ahnert and Kakhbod (2017). We depart from this literature by analyzing how regulations that mitigate liquidity risk during crises affect banks' exposure to other kinds of risk. In particular, we empirically identify how the RR and the LCR affect a bank's attitude toward credit risk in its loan portfolio.

This paper is also related to a discussion of the tradeoffs associated with liquidity regulations. Perotti and Suarez (2011) show that taxes can be used as a liquidity regulation to correct for fire sale externalities in short-term funding markets. Diamond and Kashyap (2016) show that liquidity regulations with a structure like the LCR can correct for inefficient investment in liquid assets owing to depositors' incomplete information about a bank's resilience to liquidity stress. Allen and Gale (2017) surveys the literature and concludes that it has not converged on a paradigm for understanding the role of liquidity regulations. This paper contributes to this literature by illustrating how the effectiveness of liquidity regulations in supporting financial stability depends on how they also affect the degree to which banks take risk with their ineligible assets.

This paper also contributes to an empirical literature looking at the effects of liquidity regulations on banks. This paper is specifically related to work on the RR that explores its institutional structure and historical uses (Feinman (1993)), its effectiveness in mitigating liquidity stress (Carlson (2015)), and its effects on other bank characteristics

[4]This paper also relates more generally to a vast literature on banking. See, for example, work on banking failures and crises (Caballero (2010), Caballero and Krishnamurthy (2008), Ashcraft (2005), Baltensperger (1980)), contagion (Acemoglu, Ozdaglar and Tahbaz-Salehi (2015)), shadow banking (Gennaioli, Shleifer and Vishny (2013)), loan supply effects of monetary policy and bank financing constraints (Kashyap, Stein and Wilcox (1993), Paravisini (2008)), the effects of banking regulations on credit supply and risky lending (Di Maggio and Kermani (2017), Di Maggio, Kermani and Korgaonkar (2019)), corporate governance (Ivashina et al. (2009)), the role of supervisory policies on bank lending and external financing (Beck, Demirguc-Kunt and Levine (2006)), and monopoly banking with uncertainty (Prisman, Slovin and Sushka (1986)).

(Curfman and Kandrac (2018)). It is also related to work that examines the effect of recent liquidity regulations. Banerjee and Mio (2018) show that the Individual Liquidity Guidance, a precursor to the LCR in the UK, led banks to decrease lending to financial firms, but they do not find evidence that it reduced the amount of lending to non-financial firms. Bonner and Eijffinger (2016) show that a precursor of the LCR in the Netherlands was associated with higher long-term interbank lending rates. In the US, Roberts, Sarkar and Shachar (2018) show that the LCR in the US has been associated with reduced liquidity creation, while Sundaresan and Xiao (2019) provide evidence that the LCR led banks to acquire liquidity by borrowing more from the Federal Home Loan Banks.

3 Model

This section introduces a model of bank risk-taking in the presence of liquidity risk and liquidity requirements. It illustrates channels by which tightening liquidity requirements can either increase or decrease the incentive for banks to invest the remaining illiquid part of their portfolios in risky assets. It also shows that the risk-motivating effect is more likely to dominate when the capacity to respond to liquidity stress is high. Finally, it demonstrates how these incentives affect the optimal level of liquidity requirements from the perspective of a government that seeks to minimize deposit insurance payouts.

3.1 Environment

As an overview of the model, there are three dates $t = 0, 1, 2$. At date $t = 0$, a limited liability commercial bank acquires funding, allocates liquid assets to meet liquidity requirements, and chooses whether to invest the remainder of its portfolio in risky or safe long-term assets. At date $t = 1$, a liquidity shock may occur, in which case a fraction of depositors withdraw early. The bank can repay these depositors by paying out of its liquid assets and, if necessary, by selling a fraction of its illiquid investments on the long-term debt market to generate additional funds. If the bank cannot fully repay the early depositors, then it defaults in period 1, which corresponds to experiencing a run. At date $t = 2$, the bank's investment yields a return. The bank then repays the late depositors and keeps the remainder as a profit. If the return is insufficient to fully repay the late depositors, then the bank defaults. If the bank defaults in either period, then the bank is liquidated and its assets are redistributed to the depositors.

More specifically, at date $t = 0$, the bank acquires funding from a mass 1 of depositors that each invests 1 unit in the bank. The depositors are protected by deposit insurance. Because depositing in the bank is riskless, the bank pays the short-term gross interest rate R_{st} on deposits withdrawn in period 2. Deposits withdrawn in period 1 are returned without interest.[5] For simplicity, there is no other source of bank funding.

The bank invests in a combination of liquid and illiquid assets. Liquidity regulations require the bank to hold a fraction l of liquid assets, which maintain their value (or generate a gross return of 1), in period 1 and generate a return in period 2 that is equal to the short-term interest rate R_{st}.[6] The bank can invest the remainder of its funds in long-term assets that are either safe ($i = s$) or risky ($i = r$).[7] The long-term assets generate a return $\tilde{\mu}_i$. In particular, safe assets generate a riskless return of μ while risky assets generate a return of either 2μ or 0, each with probability 1/2. Note that the two types of assets generate the same expected return μ, but the risky assets exhibit greater volatility.

At date $t = 1$, a liquidity shock occurs with probability q. In that case, a fraction λ of depositors withdraw their investment with no interest. Banks can pay depositors from their liquid asset stock.[8] If the bank has insufficient liquid assets to pay the early depositors, it can sell a fraction of its illiquid assets on the long-term debt market. The bank faces a perfectly elastic demand for its long-term. Safe assets sell at the price $p_s = p$, while risky assets sell at the lower price $p_r = \delta p$, where $\delta \in (0,1)$ to reflect a risk-averse market.

The equity value of the bank is then equal to

$$V = \underbrace{(1-q)}_{\text{normal times}} \mathbf{E}_{\tilde{\mu}_i}\Bigg[\underbrace{\tilde{\mu}_i(1-l)}_{\text{ret. on long-term assets}} + \underbrace{lR_{st}}_{\text{ret. on liquid}} - \underbrace{R_{st}}_{\text{return to dep.}}\Bigg]^+$$
$$+ \underbrace{q}_{\text{liquidity stress}} \mathbf{E}_{\tilde{\mu}_i}\left[\underbrace{\tilde{\mu}_i\left(1-l-\frac{\lambda-l}{p_i}\mathbf{1}_{\lambda>l}\right)}_{\text{ret. on long-term assets}} + \underbrace{(l-\lambda)R_{st}\mathbf{1}_{l>\lambda}}_{\text{ret. on liquid}} - \underbrace{(1-\lambda)R_{st}}_{\text{return to late dep.}}\right]^+$$

where $[A]^+ = \max\{A, 0\}$ and $\mathbf{1}_A$ is an indicator function that is equal to 1 when A holds and is 0 otherwise. Taking the expectation over the return of the long-term assets, the

[5] See Section 3.5 for an extension of the model in which the bank can also pay interest on deposits that are withdrawn in period 1.

[6] Liquid assets can be interpreted to include cash, reserves, and some types of securities, similar to Berger and Bouwman (2009). See Section 3.5 for an extension of the model in which the return on liquid assets can be different from 1 in period 1 and different from R_{st} in period 2.

[7] The long-term assets can be interpreted as loans.

[8] For simplicity, there are no penalties for using liquid assets to respond to liquidity stress. To consider the effect of penalties, see Section 3.5 for an extension of the model that allows for variation in the return on liquid assets in period 1. In particular, a penalty can be represented by decreasing this return.

first term averages over states in which there is no liquidity shock, or normal times. In those states, the bank accrues the remainder of the return from its liquid and illiquid assets after paying off the depositors. The payoff is restricted to be nonnegative due to limited liability.

The second term averages over states in which a liquidity shock occurs. If the bank's liquid assets are insufficient to repay the early depositors, or $\lambda > l$, then the bank must sell a fraction of its long-term assets in the debt market to generate additional funds. The bank can default in period 1 if selling all of its illiquid assets does not generate enough funds to pay the early depositors:

$$p_i(1-l)+l<\lambda$$

If the bank can generate enough funds to avoid a run, then it maintains $1-l-\frac{\lambda-l}{p_i}$ units of long-term assets. The bank can also default in period 2 if the return from its residual holdings of long-term assets is insufficient to repay the late depositors:

$$\tilde{\mu}_i\left(1-l-\frac{\lambda-l}{p_i}\right)<(1-\lambda)R_{st}$$

If the return is sufficient to repay the late depositors, then the bank accrues the remainder as a profit.

Figure 2 summarizes the determination of the bank's equity value.

We assume $q<\delta p$, and $\mu>\max\left\{R_{st},\frac{1-q}{1-\frac{q}{p}}R_{st},\frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R_{st}\right\}$ to ensure that it is not profitable for the bank to hold more than the required level of liquid assets.

Proposition 1. *If $q<\delta p$ and $\mu>\max\left\{R_{st},\frac{1-q}{1-\frac{q}{p}}R_{st},\frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R_{st}\right\}$, then the bank never wants to hold more than the required level of liquid assets.*

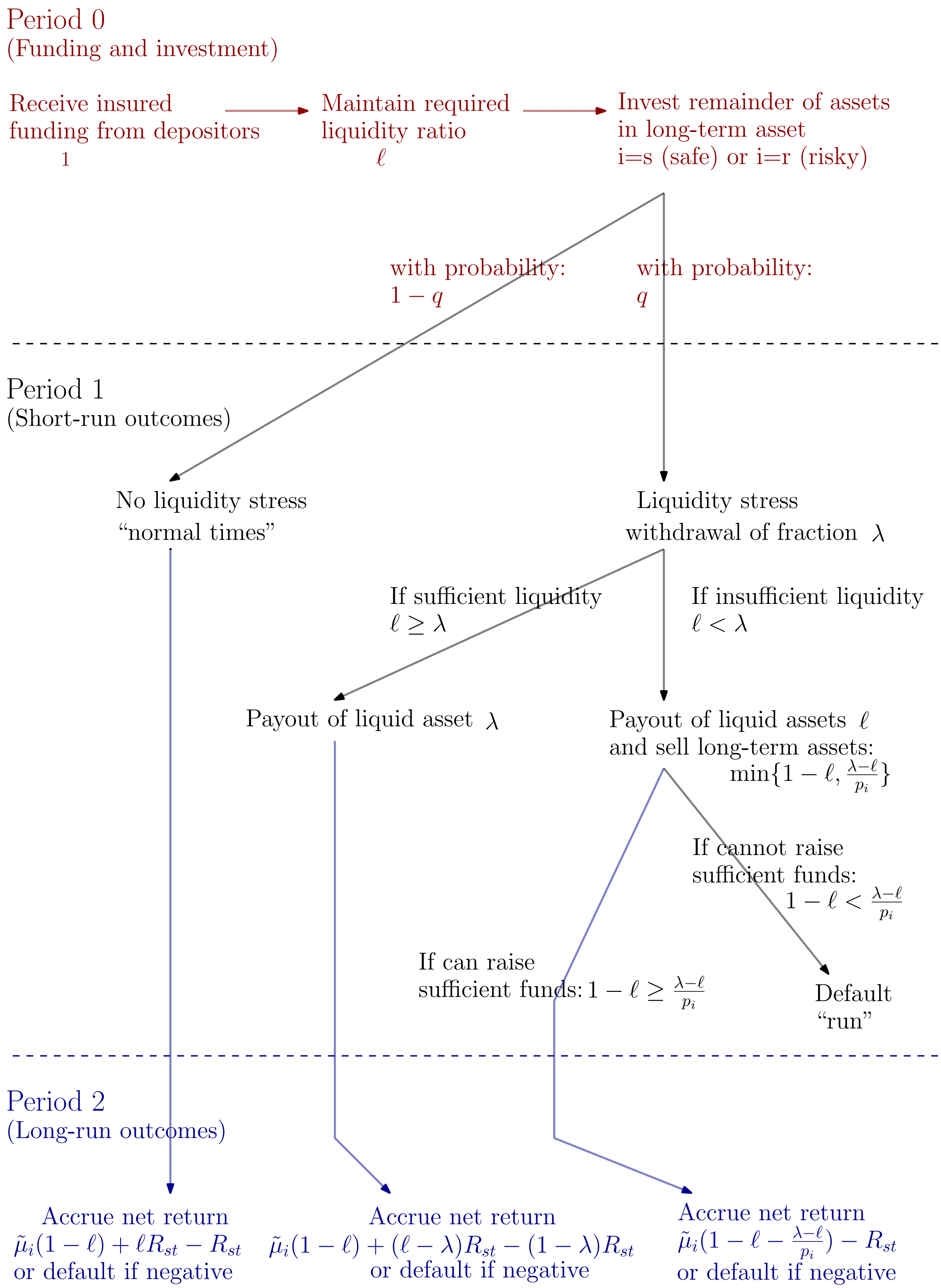
Proof. See Appendix. □

The intuition is that holding liquid assets has the benefit of improving the bank's performance in the liquidity stress state, but it also has an opportunity cost associated with reducing the bank's investment in higher-yield long-term assets. Assuming a high expected return on long-term assets μ and a low probability of the liquidity shock state q ensures that the cost always exceeds the benefit in expectation.

We also assume $p<1$ to ensure that holding liquid assets increases the bank's capacity to respond to liquidity stress.

Proposition 2. *If $p<1$, then holding liquid assets increases the probability that the bank does not default due to liquidity stress.*

Figure 2: The sequence of events in the model.



Proof. See Appendix. □

The intuition is as follows. On the one hand, holding greater liquid assets can improve the bank's performance in the liquidity shock state because it decreases the amount of long-term assets it needs to liquidate. On the other hand, it can also reduce the bank's ability to generate a large enough return to pay the late depositors since it decreases the bank's investment higher-yield in long-term assets. Restricting to $p < 1$ ensures that this benefit always exceeds the cost.

The parametric restrictions $q < \delta p$, $\mu > \max\left\{\frac{1-q}{1-\frac{q}{p}}R_{st}, \frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R_{st}\right\}$, and $p < 1$ are assumed for the rest of the analysis.[9]

3.2 Characterization of bank risk-taking

The bank chooses to invest the illiquid portion of its portfolio in either risky assets or safe assets in order to maximize its expected profits. Risky assets achieve a higher expected net return in normal times because of limited liability, whereas safe assets achieve a higher expected net return when there is a liquidity shock because they can be sold for a higher price in the debt market. The incentive to invest in risky assets is decreasing in the expected return μ. This is because banks that invest in risky assets accrue a smaller fraction of this expected return in the liquidity shock state. As a result, the bank's asset choice can be summarized by a threshold μ^* in the expected return, which can be interpreted as the propensity to take risk.

Lemma 1. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$ and invests in risky assets if $\mu < \mu^*$.*

Proof. See Appendix. □

This result is analogous to a classical idea from the financial stability literature that a bank's franchise value, or the profits it would expect to accrue as long as it remained solvent, can decrease its incentive to take risk (Keeley (1990)). The channel is based on bank equityholders' risk-shifting incentive (Jensen and Meckling (1976)). For a bank with limited liability, the payoff for the equityholders is like a call option on the value of the bank with a strike price corresponding to its debt payment. A standard result from options theory is that the value of an option increases in the volatility of the underlying asset (McDonald (2008)). By analogy, the equity value of a bank increases in the risk of its assets. Moreover, this risk-taking incentive is larger when the value is near the strike price, which in the analogy corresponds to a bank with low profitability.

[9] Note that it is not necessary to explicitly assume $\mu > R_{st}$ since $\mu > \frac{1-q}{1-\frac{q}{p}}$ and $p < 1$ imply $\mu > R_{st}$.

3.3 The effect of liquidity regulations on bank risk-taking

Requiring banks to hold a greater fraction of liquid assets can either increase or decrease the incentive to invest the illiquid portion of their portfolios in risky assets. Tightening liquidity requirements is more likely to induce greater risk-taking when banks have a greater capacity to respond to liquidity stress, such as when the liquidity requirements are already tight.

Proposition 3. *There exists a threshold $l^*(p)$ such that μ^* is decreasing in l for $l < l^*(p)$ and μ^* is increasing in l for $l > l^*(p)$. The threshold $l^*(p)$ corresponds to the minimal level of liquidity at which the bank can survive liquidity stress if it invests in risky assets.*

Proof. See Appendix. □

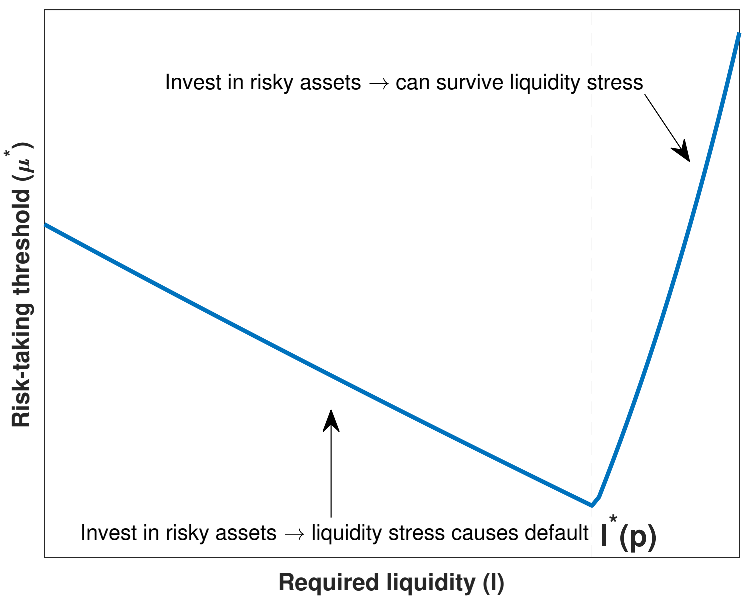
Corollary 1. *The threshold $l^*(p)$ can also be interpreted as the level of liquidity that minimizes the propensity to take risk.*

Figure 3 illustrates this result graphically. The intuition is as follows. If the bank holds few liquid assets, then a liquidity shock can cause it to default. In particular, if $l < l^*(p)$, liquidity stress causes the bank to default if it holds risky assets, but it may not cause the bank to default if it holds safe assets due to their higher liquidation value. As a result, if the bank holds risky assets, then marginally tightening liquidity requirements has no effect on the bank's equity value in the liquidity shock state. However, if the bank holds safe assets, then tightening liquidity requirements increases the bank's performance in the liquidity shock state. Therefore, tightening liquidity requirements increases the expected return of safe assets relative to risky assets, which decreases the incentive to invest in risky assets ex-ante.[10]

By contrast, if the bank has a high capacity to respond to liquidity stress, or $l > l^*(p)$, then tightening liquidity requirements increases the incentive to take risk. In particular, the bank can adequately respond to liquidity stress without defaulting, even if it invests in risky assets. In that case, tightening liquidity requirements increases the bank's equity value in the liquidity shock state relatively more if it holds risky assets. This is because it increases the extent to which the bank can respond to liquidity stress by using its own liquidity buffer rather than by liquidating its long-term assets. This mitigates the disadvantage of risky assets, which is their lower price in the debt market. This in turn increases the incentive to invest in risky assets.

[10] Note that this follows from assuming that the debt price satisfies $p < 1$ as in Proposition 2. This assumption implies that paying out liquid assets is a more efficient way to respond to liquidity stress than selling long-term assets in the debt market. By contrast, if the price p is sufficiently high, then liquidity requirements can decrease the return of safe assets in the liquidity shock state since holding liquid assets becomes less efficient than selling in the debt market. In that case, increasing the fraction of liquid assets always increases the incentive to take risk.

Figure 3: Bank asset choice and liquidity requirements. This figure plots the risk-taking threshold in the mean return μ^* as a function of the bank's required fraction of liquid assets.



By similar reasoning, tightening liquidity requirements is also more likely to induce greater risk-taking when the long-term debt price is high.

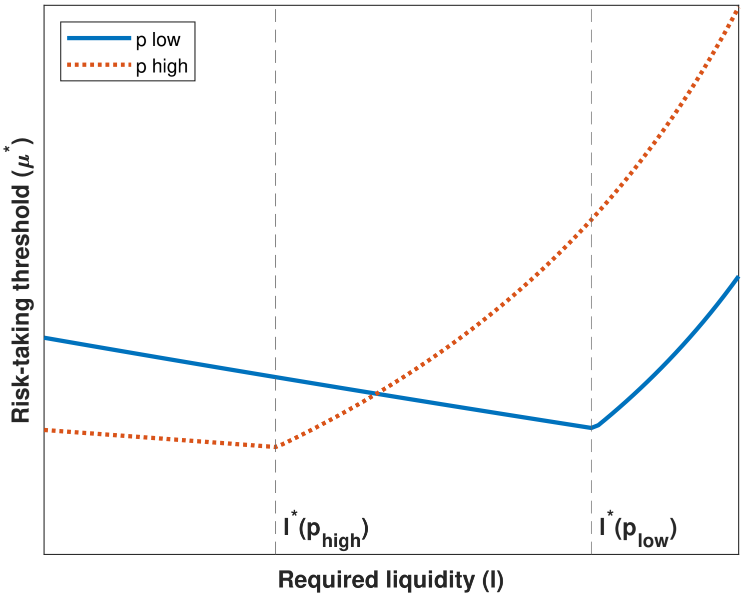
Proposition 4. *Increasing the price for long-term debt increases the range for l on which risk-taking increases in the tightness of liquidity requirements:* $\frac{dl^*(p)}{dp} < 0$.

Proof. See Appendix. □

Figure 4 illustrates this result graphically. The intuition is that increasing the long-term debt price increases the bank's capacity to respond to liquidity stress, as it reduces the fraction of the bank's long-term assets that must be sold to generate sufficient funds to pay the early depositors. This in turn decreases the probability that the bank will default. The bank therefore becomes less dependent on maintaining a buffer of liquid assets to avoid default. This induces a decrease in the threshold $l^*(p)$ at which the bank can survive liquidity stress even if it invests in risky assets.[11]

[11] Incidentally, the figure also shows that increasing the price p decreases the propensity to take risk for l in the region where the bank defaults if it invests in risky assets for both the high and low price. It also shows that increasing the price increases the propensity to take risk for l in the region where the bank can survive liquidity stress for both the high and low price. The intuition and proof are closely analogous to the effect of tightening liquidity requirements (Proposition 3), as both liquidity requirements and a high liquidation value of long-term assets increase the bank's capacity to respond to liquidity stress.

Figure 4: Bank asset choice and long-term debt market price. This figure compares the risk-taking threshold in the mean return μ^* for different long-term debt market prices.



3.4 Optimal liquidity regulation

This section illustrates the optimal level of liquidity requirements from the perspective of a government that seeks to minimize deposit insurance payouts.

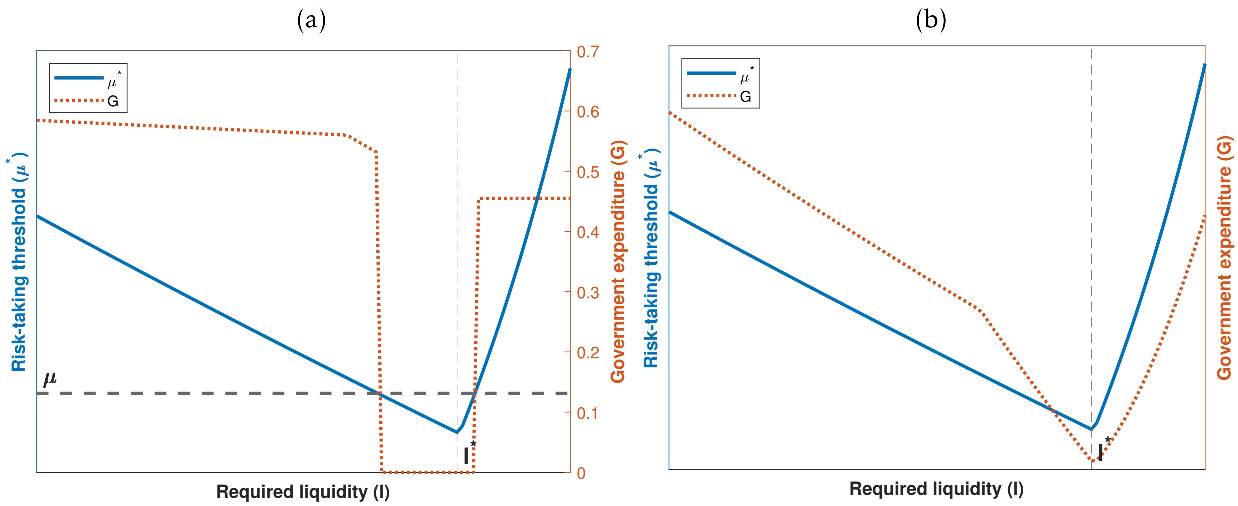
The government insures against a bank's failure to repay but does not insure against a depositor's own liquidity risk. Specifically, the government insures depositors at a gross return of R_{st} for late withdrawals and a return of 1 for early withdrawals. The total payout for depositors is then given by $T = (1 - \lambda q)R_{st} + q\lambda$. If the expected payout from banks is equal to B, then the government must pay the difference $G = T - B$. Suppose there is a mass 1 of banks whose expected return μ is distributed with cdf F.

Proposition 5. *The optimal level of liquidity that minimizes the government's expenditure, denoted by l^G, is at least as great as the level $l^*(p)$ that minimizes the fraction of banks that invest in risky assets.*

Proof. See Appendix. □

The intuition is as follows. Tightening liquidity requirements increases the amount that the bank can pay back to depositors if liquidity stress causes it to default. If liquidity is lower than $l^*(p)$, then tightening liquidity requirements also decreases the incentive for banks to invest in risky assets (Proposition 3). Both of these effects decrease government expenditure, which implies that the government's optimal liquidity level must be at least as great as the threshold $l^*(p)$. If liquidity is higher than this level, then tightening liquidity requirements instead intensifies the incentive for banks to invest in risky

Figure 5: Panel (a) depicts government expenditure for a single bank with expected return μ. Panel (b) depicts government expenditure for a mass of banks with a uniformly distributed return.



assets. The government then faces a tradeoff in which liquidity requirements increase the resilience of banks to liquidity stress but also increases their incentive to take risk with their remaining illiquid assets.

Figure 5(a) shows the government expenditure for the case of a homogenous mass of banks with expected return μ. Government expenditure is positive when the banks invest in risky assets (which occurs when $\mu < \mu^*$) and zero when the banks invest in safe assets (which occurs when $\mu > \mu^*$). Therefore any liquidity level that induces the banks to invest in safe assets is optimal for the government. Note additionally that, conditional on the banks investing in risky assets, government expenditure is decreasing in the level of the liquidity requirement. This reflects the fact that liquidity increases the capacity of the banks to respond to liquidity stress. However, government expenditure is still positive since liquidity does not eliminate the risk associated with the return on the banks' long-term assets.

Figure 5(b) shows government expenditure for the case of a mass of banks whose expected return is uniformly distributed. The optimal liquidity level that minimizes government's expenditure is approximately equal to the level $l^*(p)$ that minimizes the fraction of banks that invest in risky assets. This indicates that, for this example, the cost of liquidity requirements associated with encouraging more banks to invest in risky assets outweighs the benefit from increasing the resilience to liquidity stress for the banks that would have already chosen to invest in risky assets.

3.5 Extensions

The results of the model are robust to various extensions, including generalizing the return of the depositors who withdraw in period 1, the return on liquid assets in period 1, the return on liquid assets in period 2, and the fraction of the bank's assets that depositors can recover if the bank defaults. See Appendix Section A for further elaboration.

4 The effect of the reserve requirement on banks

The result from the model that liquidity can either increase or decrease the incentive for banks to invest the remaining illiquid portion of their portfolios in risky assets (Proposition 3) motivates an empirical analysis to determine whether either effect dominates in practice. This section empirically examines the effect of the reserve requirement (RR) on banks. Using Call Reports data, we implement a regression discontinuity design that exploits the progressive structure of the RR in the US. We find evidence that RR rates are associated with increased holdings of reserves, but we do not find evidence that RR rates are associated with changes in risk-taking.

4.1 Setting: the reserve requirement

The RR required banks to hold a fraction of net transaction accounts (NTA), which includes demand deposits and other short-term liabilities[12] net of amounts due from other depository institutions and cash items in the process of collection, as liquid reserves, which includes either vault cash or deposits with the Federal Reserve. In recent decades, the RR was primarily used as a means to facilitate the implementation of monetary policy.[13] However, the RR also functioned like a liquidity requirement with a structure that is comparable to more recent liquidity regulations like the LCR.

The most recent RR regime started in the early 1980s with the Monetary Control Act and the Garn-St. Germain Act. From 1982 until 2020, all commercial banks were subject to a progressive RR rate characterized by two thresholds in the volume of NTA. For example, in 2019, the first \$16.3 million of NTA was called the "exemption amount" and did not require any reserves. The next \$107.9 million was called the "low reserve tranche" and required reserves to be held at 3%. The remaining NTA required reserves to be held at 10%. Note that RR rates have been modified three times since 1980: in 1990 the RR rate on nonpersonal time deposits and Eurocurrency liabilities was reduced from

[12] This specifically includes automatic transfer service (ATS) accounts, NOW accounts, share draft accounts, telephone or preauthorized transfer accounts, ineligible bankers acceptances, and obligations issued by affiliates maturing in seven days or less.

[13] See Feinman (1993) for background information on the structure and historical uses of the RR.

3% to 0%, in 1992 the maximal RR rate on NTA was reduced from 12% from 10%, and in 2020 the reserve requirement was eliminated.

The thresholds mechanically adjusted each year based on a formula involving banking system aggregates. In particular, the exemption amount threshold adjusted by 80% of the previous year's growth in aggregate reservable liabilities if the growth rate was positive, otherwise it did not adjust.[14] The low reserve tranche upper threshold adjusted by 80% of the previous year's positive or negative net growth of aggregate NTA.

4.2 Data: Call Reports

This exercise uses data from filings of the Consolidated Report on Condition and Income, otherwise known as the Call Reports. All US insured commercial banks are required by the Federal Deposit Insurance Corporation to file on a quarterly basis. Our baseline sample covers the period from 1993Q1 to 2018Q4, during which time marginal RR rates were constant except for yearly adjustments of the thresholds. Note that the results for many of the RR exercises are reported for the full sample period as well as for the subsample restricting to years before 2008. We distinguish this subsample due to substantial changes that occurred during the financial crisis, including a substantial increase in reserves and the introduction of interest on reserves. We examine the effect of the discontinuous jump in marginal RR at the low reserve tranche upper threshold.

Table 1 presents summary statistics for the characteristics used in the analysis. The marginal RR rate is determined using an approximation of NTA that can be computed using the Call Reports data.[15] The remaining characteristics correspond to the CAMELS risk raking system, including the capital to assets ratio (C), the ratio of non-performing loans as a measure of asset quality and risk-taking and (A), non-interest expenses to assets as a measure of managerial efficiency (M), return on assets as a measure of earnings (E), an approximation of reserves to NTA as a measure of liquidity (L),[16] and the absolute difference between short-term assets and liabilities as a measure of sensitivity to market risk (S). Non-categorical variables are winsorized at 1% in each year.

[14] Reservable liabilities include NTA, nonpersonal time deposits, and Eurocurrency liabilities.

[15] Specifically, we compute NTA as total transaction accounts minus, where available, cash deposits in the process of collection and unposted debits, balances due from depository institutions in the US, and balances due from banks in foreign countries and foreign central banks.

[16] Specifically, we compute reserves as currency and coin plus balances due from Federal Reserve Banks.

4.3 Specification: regression kink design

We estimate the following baseline regression kink design (RKD) specification based on the change in marginal RR rates at the low reserve tranche upper threshold:

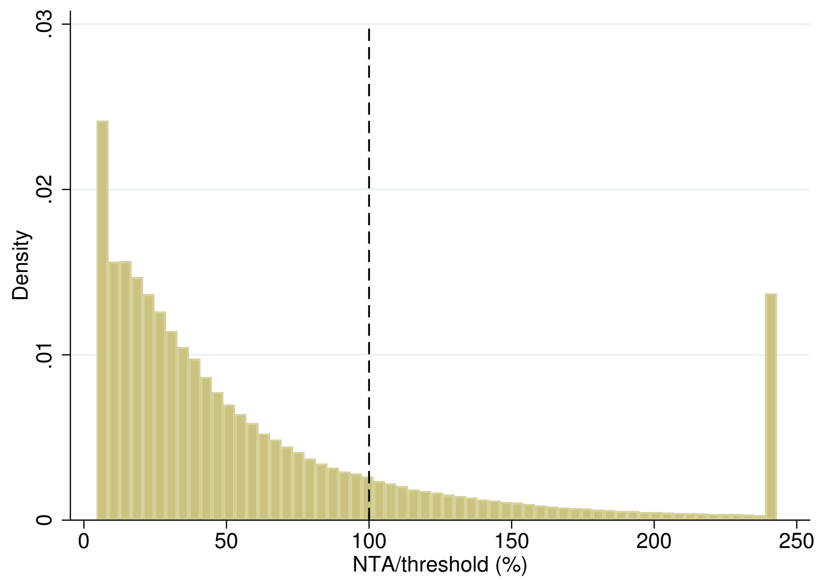
$$Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \epsilon_{it} \tag{1}$$

where Y_{it} is the dependent variable (the reserves to NTA ratio as a measure of liquidity or the non-performing loans ratio as a measure of risk-taking) for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's NTA and low reserve tranche upper threshold, and D_{it} indicates whether a bank's NTA exceeded the threshold. The regression kink estimate is obtained by dividing δ, which corresponds to the change in the slope of the dependent variable at the threshold, by the change in the marginal RR rate 10%-3%=7%. T-statistics computed using bank-clustered standard errors are reported in parentheses. This specification is implemented with a bandwidth of 30% and a rectangular kernel. In some estimations we also include a set of lagged controls that includes bank size and proxies for indicators from the CAMELS risk rating system (excluding the dependent variable) as well as time fixed effects. Note that the control variables and fixed effects are included to reduce sampling variation, although they are not necessary for identification in a RKD.

To achieve identification, the RKD mitigates potential confounding due to systematic differences between banks whose NTA are smaller or larger than the threshold. The identification assumption is that, for a bank near the threshold, its position on either side of the threshold is as good as randomly assigned. This assumption is supported if banks cannot perfectly manipulate their treatment status, which is evidenced by a smooth density in the assignment variable (Card et al. (2015)). This is plausible since considerations other than the RR are also likely to determine a bank's level of NTA, such as the activities of depositors or the bank's incentive to respond to market conditions. Additionally, Figure 6 plots the pooled distribution of banks by the ratio of NTA to the low reserve tranche upper threshold. The fact that there is no visible bunching around the threshold suggests that banks do not manipulate their volume of NTA to affect their RR rates. We also implement the density estimation and discontinuity test proposed in Cattaneo, Jansson and Ma (2019) and do not find statistically significant evidence of assignment manipulation at the 5% significance level.

To further assess the identification assumption, we show that the treatment and control samples are balanced with respect to lagged covariates. In particular, Online Appendix Section F shows binned scatter plots for the logarithm of assets, capital ratio, non-interest expenses to assets ratio, return on assets, and sensitivity to market risk. It

Figure 6: Distribution of NTA. This figure plots the pooled distribution of banks by the ratio of NTA to the low reserve tranche upper threshold. The sample is winsorized at 5%.



also shows the predicted values from estimating linear regressions for the subsample of observations within a 30% deviation within the threshold over the whole sample period. The coefficient δ from estimating the regression in equation (1) is insignificant for all of these characteristics except the sensitivity to market risk.

4.4 Results

Table 2 shows the results from estimating equation (1) within a bandwidth of 30% around the low reserve tranche upper threshold using the reserves to NTA ratio as the dependent variable. Column (1) reports the coefficient on the treatment indicator when estimating the regression on the full sample period without the controls and time fixed effects, column (2) includes the controls and fixed effects, and columns (3) and (4) report the corresponding results from on a subsample restricting to years before 2008. The estimated effect is positive and significant, indicating that a 1% increase in RR rates is associated with a 1.6 basis point increase in the reserves to NTA ratio. This is consistent with Figure 1(a), which shows a corresponding binned scatterplot corresponding to the estimation in column (1).

By contrast, Table 3 and Figure 10 show that the RR is not significantly associated with non-performing loans.

5 The effect of the liquidity coverage ratio on banks

This section empirically examines the effects of the liquidity coverage ratio (LCR) on the extent to which banks take risk with their illiquid assets. We implement a difference-in-differences design exploiting the introduction of the LCR for a subset of bank holding companies (BHCs) in 2015. We find that the LCR was associated with increased liquidity, but we do not find that it was associated with significant variation in non-performing loans. Finally, we do not find that the LCR was associated with a significant change in credit default swap (CDS) jumps during the COVID-19 crisis compared to the global financial crisis.

5.1 Setting: liquidity coverage ratio

The LCR was introduced at Basel III in December 2010 in response to the observed liquidity stress during the 2008 financial crisis. The LCR requires BHCs to hold a certain percentage of high quality liquid assets (HQLA) relative to net cash outflows over a 30-day stress period. The following assets contribute to HQLA: excess reserves, Treasury securities, government agency debt and MBS, and sovereign debt with zero risk-weights contribute without any discount, government-sponsored agency (GSE) debt, GSE MBS, and sovereign debt with risk-weights less than 20% contribute at a 15% discount, and investment-grade (IG) debt by non-financial corporations, IG municipal debt, and equities contribute at a 50% discount. Net cash outflows associated with a bank's liabilities are computed based on their maturity, stability, whether they are insured, whether they are foreign or domestic, and whether they are retail or wholesale. See Hong, Huang and Wu (2014) or Roberts, Sarkar and Shachar (2018) for more details about the computation of high quality liquid assets and net cash outflows.

The US implementation of the LCR was proposed in October 2013, finalized in September 2014, and phased-in from January 2015 to January 2017. It applies to BHCs with total assets exceeding $250 billion or on-balance sheet foreign exposure exceeding $10 billion. A modified LCR of 70% applies to BHCs with assets between $50 billion and $250 billion.

5.2 Data: FR Y-9C

This exercise uses data from quarterly FR Y-9C filings by BHCs. We construct a balanced sample for the period from 2010Q1 until 2018Q4.

Table 4 presents summary statistics for various bank characteristics, including an indicator for whether a bank is subject to either the 70% LCR or the 100% LCR as well as characteristics corresponding to the CAMELS risk rating system. The CAMELS characteristics are similar to the ones described in Section 4.2 except that liquidity is represented by the ratio of HQLA to total assets to match the LCR. HQLA is computed using the LCR weights for the different asset categories. Similar to Roberts, Sarkar and Shachar (2018), HQLA is approximated using the FR Y-9C data as follows: cash assets, federal funds sold, treasury securities, and agency debt and MBS contribute without discount, GSE debt and MBS contribute at a 15% discount, and municipal securities and equity securities contribute at a 50% discount. Non-categorical variables are winsorized at 1% in each year.

5.3 Specification: difference-in-differences

We estimate the following difference-in-differences specification:

$$Y_{it} = \beta LCR_i \times post2013Q3_t + \gamma controls_{it-1} + \psi_i + \phi_t + \epsilon_{it} \tag{2}$$

where Y_{it} is one of the outcome variables (the liquid assets ratio as a measure of liquidity or the non-performing loans ratio as a measure of risk-taking) for bank i in quarter t, LCR_i is an indicator for whether a bank was subject to either the 100% or 70% LCR at the implementation date of 2015Q1, $post2013Q3_t$ is an indicator for quarters greater than or equal to the proposal date of 2013Q3, $controls_{it-1}$ is a set of lagged control variables, ψ_i represent bank fixed effects, and ϕ_t represent time fixed effects. We consider the LCR to be effective as of the proposal date to account for the possibility that BHCs would attempt to smoothly transition to compliance with the LCR by its implementation date. The set of controls includes the logarithm of total assets and proxies for indicators from the CAMELS risk rating system, as described in Section 5.2. The controls are lagged by one quarter to mitigate endogeneity, and we exclude the dependent variable from the controls. T-statistics computed using bank-clustered standard errors are reported in parentheses.

The difference-in-differences methodology mitigates potential confounding due to aggregate trends or systematic differences between treated and untreated banks. The coefficient β represents the degree to which banks subject to the LCR changed from before to after the introduction of the LCR relative to other banks. The identification assumption is that the treated and untreated groups would have experienced parallel trends in the absence of the policy intervention. To assess the relative trend between the two groups before and after the introduction of the LCR in 2015, we also estimate a version of this regression with yearly treatment effects

$$Y_{it} = \sum_{t \neq 2013Q3} \beta_t LCR_i \times \phi_t + \gamma controls_{it-1} + \psi_i + \phi_t + \epsilon_{it} \tag{3}$$

where LCR_i is the indicator for whether a bank was subject to the 100% LCR or the 70% LCR, the coefficients β_t represent the differential trend of the treatment group compared to the control group over the sample period, and the other variables are the same as above.

Figure 11 presents the coefficients β_t from estimating equation (3) for the set of dependent variables. The results for the HQLA ratio are generally consistent with the parallel trends assumption, as the yearly effects associated with the relative trend of the treatment group are generally evenly distributed around zero in the period before the introduction of the stress tests. The results for the non-performing loans ratio are consistent with the parallel trends assumption starting in 2012Q1, although there are fluctuations in the relative trend from 2010Q1 to 2012Q1.

To further address endogeneity concerns, Table 5 compares the treatment and control groups with respect to the control variables in the period before the introduction of the LCR. It shows the mean for each variable and group in the period preceding the LCR. It also shows the t-statistic on the coefficient η from estimating the regression

$$Y_{it} = \eta LCR_i + \phi_t + \epsilon_{it}$$

where Y_{it} represents one of the control variables from equation (2). The two groups exhibit a statistically significant difference in total assets, which is unsurprising since eligibility for the LCR depends on a threshold in total assets. The only other characteristic for which the two groups exhibit a statistically significant difference is the capital ratio. The similarity between the two groups with respect to the majority of characteristics reduces the concern that systematic differences between the two groups that are correlated with the timing of the LCR could confound the results.

5.4 Results

Table 6 presents the coefficients from estimating equation (2) using an indicator for banks subject to the 100% LCR, an indicator for banks subject to the 70% LCR on a subsample omitting banks that were subject to the 100% LCR, and an indicator for banks subject to either the 100% LCR or the 70% LCR. The coefficient for banks subject to either version of the LCR is positive and significant, indicating that the LCR was associated with a relative increase in the liquid assets ratio of around 3.4%. The results for the 100% LCR and the 70% LCR are similar.

By contrast, Table 7 indicates that the LCR was not significantly associated with risk-taking.

5.5 CDS spreads

This section considers the effect of the LCR on overall bank risk as measured by increases in credit default swap (CDS) spreads during crises. A CDS is like an insurance contract in which the purchaser pays a premium, which is called the CDS spread, in return for a payoff conditional on a credit event, such as default, of a reference entity. CDS spreads are therefore positively associated with the credit risk of the reference entity (Augustin et al. (2014), Sarin and Summers (2016)).

Figure 7 shows the mean CDS spread for a balanced subsample of BHCs for which we could obtain CDS spread data from Bloomberg and Refinitiv's Datastream database. The figure compares the mean CDS spread for 6 BHCs that were subject to the 100% LCR and 2 BHCs that were subject to the 70% LCR.[17] The figure indicates that CDS spreads for both groups of banks exhibited a larger increase during the global financial crisis, which occurred before the introduction of the LCR, compared to the COVID-19 crisis, which occurred after the introduction of the LCR. Figure 8 and Figure 9 additionally show how the distribution of the CDS jumps during the two crises changed for the two groups of BHCs.

There are many factors that could have affected the relative magnitudes of CDS spread responses between these two crises, including the nature of the shock, the magnitude of the shock, policy responses, and ex-ante regulations. To better isolate the effect of liquidity regulations, we implement a difference-in-differences design by comparing the two groups, which have differential exposure to the LCR, with respect to the change in CDS spread jumps between the two crises. In particular, we estimate the specification

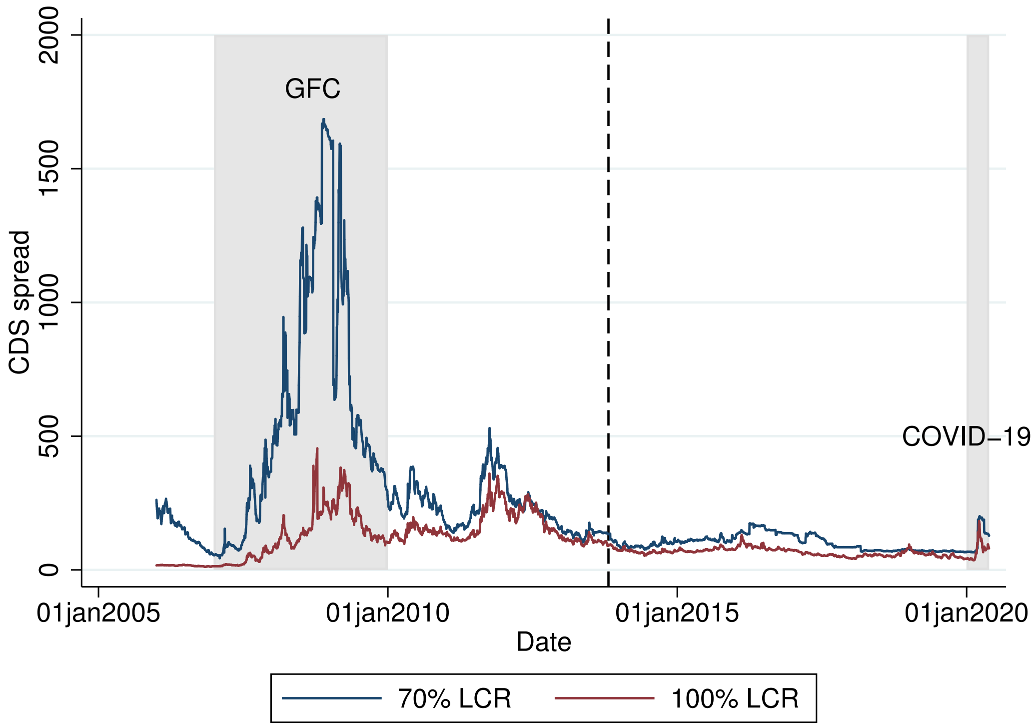
$$Y_{it} = Post_t + \beta LCR_i \times Post_t + \psi_i + \epsilon_{it}$$

where Y_{it} is the difference between the maximum and the minimum of the CDS spread in period t, LCR_i is an indicator for whether a bank was subject to the 100% LCR as of the implementation date of 2015Q1, $Post_t$ is an indicator that equals 1 for the COVID-19 crisis (corresponding to dates in 2020) and 0 for the global financial crisis (corresponding to dates in 2007-2009), and ψ_i represent bank fixed effects. T-statistics with standard errors are clustered by bank.

Table 8 presents the results. The LCR is not significantly associated with changes in

[17] Note that CDS data is not available for this sample period for any banks that are not subject to either the 100% LCR or the 70% LCR.

Figure 7: CDS spread. This figure shows the mean CDS spread for a balanced subsample of BHCs for which we could obtain CDS spread data from Bloomberg and Refinitiv's Datastream database. The figure compares the mean CDS spread for 6 BHCs that were subject to the 100% LCR and 2 BHCs that were subject to the 70% LCR.



CDS spreads during crises.

6 Conclusion

This paper introduces a model to illustrate channels by which liquidity requirements can either increase or decrease the incentive for banks to take risk with their illiquid assets, such as loans. On the one hand, improving resilience to liquidity stress increases the expected losses from risky lending. On the other hand, holding more liquid assets decreases the need for banks to liquidate their long-term assets to generate funds in times of liquidity stress, which can in turn increase the incentive to invest in risky assets with lower liquidation values. The latter effect is more likely to dominate when banks have a high capacity to respond to liquidity stress, such as when the price for long-term debt is high. By illustrating channels by liquidity risk interacts with credit risk, our analysis sheds light on the potential side effects of liquidity regulation on financial stability.

Figure 8: This figure shows the density of CDS spread jumps for BHCs subject to the 100% LCR and BHCs subject to the 70% LCR for the global financial crisis and the COVID-19 crisis.

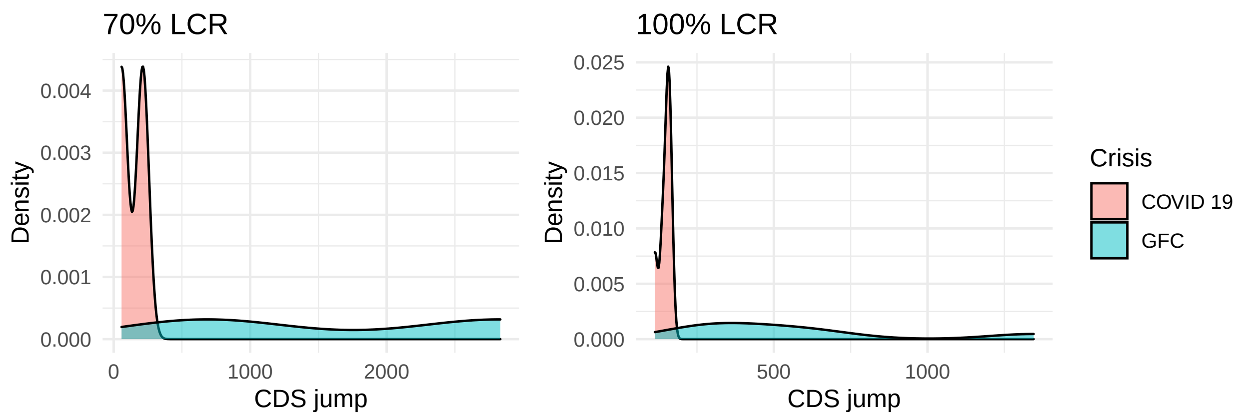
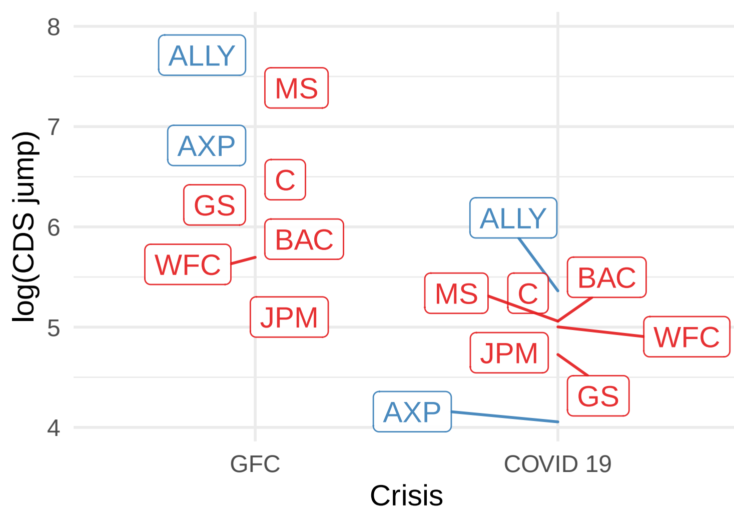


Figure 9: This figure shows the CDS spread jumps (in log scale, for visibility) for BHCs subject to the 100% LCR (red) and banks subject to the 70% LCR (blue) for the global financial crisis and the COVID-19 crisis. The BHCs in our sample are identified by stock ticker.



This paper also empirically assesses how the reserve requirement (RR) and the liquidity coverage ratio (LCR) have affected liquidity and risk-taking for US banks. We show using a regression discontinuity design that the RR did not appear to significantly affect bank risk-taking as measured by the non-performing loans ratio. We also show using a difference-in-differences methodology that the LCR also did not significantly affect the non-performing loans ratio or jumps in CDS spreads during crises.

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Appendices

A Extensions

This section describes parametric restrictions under which the main theoretical results of the model are preserved in an extension that generalizes the return of the depositors who withdraw in period 1, the return on liquid assets in period 1, the return on liquid assets in period 2, and the fraction of the bank's assets that depositors can recover if the bank defaults. In the generalized model, denote the return of depositors who withdraw in period t by $R_{d,t}$, the return on liquid assets in period t by $R_{l,t}$, the recovery rate as $w \in [0,1]$. Note that in the baseline model we have $R_{d,1} = 1$, $R_{l,1} = 1$, $R_{l,2} = R_{d,2} = R_{st}$, and $w = 1$.

We maintain analogous parametric restrictions as in the original model (see Section 3.1): $qR_{l,1} < \delta p$, $p < R_{l,1}$, and $\mu > \max\left\{\frac{1-q}{1-\frac{R_l q}{p}} R_{l,2}, \frac{1}{2}\frac{1-q}{1-\frac{R_l q}{\delta p}} R_{l,2}\right\}$.[18] We also introduce the following additional restrictions: $R_{l,1} \geq R_{d,1} \geq lR_{l,1}$, $R_{l,2} \geq R_{d,2} \geq lR_{l,2}$, and $\frac{R_{d,2}}{R_{l,2}} \geq \frac{R_{d,1}}{R_{l,1}}$. The following elaborates on the intuition behind why these additional restrictions are important for maintaining the main results of the model.[19]

Proposition 6. *The bank never wants to hold more than the required level of liquid assets.*

Proof. See Appendix. □

The intuition for this result is the same as in Proposition 1 and does not involve the additional restrictions.

Proposition 7. *Holding liquid assets reduces the probability that a liquidity shock causes the bank to default.*

Proof. See Appendix. □

This result uses the assumptions $R_{l,1} \geq R_{d,1}$ and $R_{l,2} \geq R_{d,2}$. These assumptions ensure that the bank cannot default from liquidity stress if it maintains enough liquid assets to pay all the early depositors. In particular, $R_{l,1} \geq R_{d,1}$ implies that the bank does not need to maintain a large fraction of liquid assets in order to meet the liquidity demand in period 1, and $R_{l,2} \geq R_{d,2}$ implies that the return the bank pays to the late depositors is not too large compared to its own return on assets.

[18] Note that the last two assumptions also imply $\mu > R_{l,2}$.

[19] Many of these assumptions are also intuitively natural: $R_{l,t} \geq R_{d,t}$ for $t = 1,2$ could be interpreted to represent the bank's superior expertise with respect to investing in liquid assets compared to depositors, and $R_{d,t} \geq lR_{l,t}$ for $t = 1,2$ could be interpreted to represent the idea that banks are sufficiently invested in long-term investments such as loans that they require a positive return on these assets to avoid default.

Proposition 8. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$ and invests in risky assets if $\mu < \mu^*$. Moreover, there is a threshold $l^*(p)$ such that μ^* is decreasing in l for $l < l^*(p)$ and μ^* is increasing in l for $l > l^*(p)$.*

Proof. See Appendix. □

This result uses the assumptions $R_{d,1} \geq lR_{l,1}$ and $R_{d,2} \geq lR_{l,2}$, which ensure that the bank pays a net cost on the liquid part of its portfolio (i.e. liquid assets and deposits). This in turn provides an incentive to invest the remaining illiquid assets in risky assets since they have a higher net return in period 2 due to limited liability. The result that μ^* is increasing for $l > l^*(p)$ also uses the assumption $\frac{R_{d,2}}{R_{l,2}} \geq \frac{R_{d,1}}{R_{l,1}}$. In particular, increasing liquid assets increases the incentive to take risk by mitigating the disadvantage of risky assets associated with having a lower price on the debt market in period 1. However, it also mitigates the advantage of risky assets associated having a higher net return in period 2 due to limited liability. This assumption ensures that the period 2 advantage of risky assets is large compared to the period 1 disadvantage, which in turn implies that the proportional effect from increasing liquidity requirements is smaller.

Proposition 9. *Increasing the price for long-term debt increases the range for l on which risk-taking increases in the tightness of liquidity requirements: $\frac{dl^*(p)}{dp} < 0$.*

Proof. The proof is closely analogous to the proof of Proposition 4. □

The intuition for this result is the same as in Proposition 4 and does not involve the additional restrictions.

Proposition 10. *The optimal level of liquidity that minimizes the government's expenditure, l^G, is at least as great as the level $l^*(p)$ that minimizes the fraction of banks that invest in risky assets.*

Proof. See Appendix. □

The intuition for this result is the same as in Proposition 5 and does not involve the additional restrictions.

B Omitted Proofs

B.1 Proof of Proposition 1

Proposition 1. *If $q < \delta p$ and $\mu > \max\left\{R_{st}, \frac{1-q}{1-\frac{q}{p}}R_{st}, \frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R_{st}\right\}$, then the bank never wants to hold more than the required level of liquid assets.*

Suppose the bank invests in risky assets. If the bank defaults in the liquidity stress state, then the expected value is

$$V_r^d = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{st} - R_{st}] > 0$$

Note that this is positive since $\mu > R_{st}$, which in turn follows from assuming $p < 1$ and $\mu > \frac{1-q}{1-\frac{q}{p}} R_{st}$. Then we have

$$\frac{dV_r^d}{dl} = \frac{1}{2}(1-q)[-2\mu + R_{st}] < 0$$

since $\mu > R_{st}$. If the bank can remain solvent in the face of liquidity stress, then the expected value is

$$\begin{aligned} V_r^s = &\frac{1}{2}(1-q)\,[2\mu(1-l) + lR_{st} - R_{st}] \\ &+ \frac{1}{2}q\left[2\mu\left(1-l-\frac{\lambda-l}{\delta p}\mathbf{1}_{\lambda>l}\right) + (l-\lambda)R_{st}\mathbf{1}_{l>\lambda} - (1-\lambda)R_{st}\right] \end{aligned}$$

Note that

$$\begin{aligned} \frac{dV_r^s}{dl} &= \frac{1}{2}(1-q)[-2\mu + R_{st}] - q\mu + q\mu\frac{1}{\delta p}\mathbf{1}_{\lambda>l} + \frac{1}{2}qR_{st}\mathbf{1}_{l>\lambda} \\ &= \left[-\mu\left(1-\frac{q}{\delta p}\right) + \frac{1}{2}(1-q)R_{st}\right]\mathbf{1}_{\lambda>l} \\ &\quad + \frac{1}{2}[-2\mu + R_{st}]\mathbf{1}_{l>\lambda} < 0 \end{aligned}$$

since $q < \delta p$ and $\mu > \frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}} R_{st}$.

Suppose the bank invests in safe assets. If liquidity stress causes the bank to default in either period, then the expected value is

$$V_s^d = (1-q)[\mu(1-l) + lR_{st} - R_{st}] > 0$$

Note that

$$\frac{dV_s^d}{dl} = (1-q)[-\mu + R_{st}] < 0$$

since $\mu > R_{st}$. If the bank can remain solvent in the face of liquidity stress, then the expected value is

$$V_s^s = (1-q)[\mu(1-l) + lR_{st} - R_{st}] \\ + q\left[\mu\left(1 - l - \frac{\lambda - l}{p}\mathbf{1}_{\lambda > l}\right) + (l-\lambda)R_{st}\mathbf{1}_{l>\lambda} - (1-\lambda)R_{st}\right]$$

Note that

$$\frac{dV_s^s}{dl} = (1-q)[-\mu + R_{st}] - q\mu + q\mu\frac{1}{p}\mathbf{1}_{\lambda>l} + qR_{st}\mathbf{1}_{l>\lambda} \\ = \left[-\mu\left(1-\frac{q}{p}\right) + (1-q)R_{st}\right]\mathbf{1}_{\lambda>l} \\ + [-\mu + R_{st}]\mathbf{1}_{l>\lambda} < 0$$

since $q < \delta p$ (which also implies $q < \delta p < p$) and $\mu > \frac{1-q}{1-\frac{q}{p}}R_{st}$.

B.2 Proof of Proposition 2

Proposition 2. *If $p < 1$, then holding liquid assets increases the probability that the bank does not default due to liquidity stress.*

First, we derive conditions under which the bank defaults in period 1, which can also be interpreted as a run:

- If the bank invests in risky assets, it experiences a run if $l < \zeta_r \equiv \frac{\lambda - \delta p}{1 - \delta p}$
- If the bank invests in safe assets, it experiences a run if $l < \zeta_s \equiv \frac{\lambda - p}{1-p}$

Clearly, increasing l always reduces the probability of default in period 1.

Second, we derive conditions under which the bank can repay the early depositors but then defaults in period 2. If the bank invests in risky assets and the assets generate a positive return, then the bank's payoff in the liquidity shock state is

$$2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\mathbf{1}_{\lambda>l}\right) + (l-\lambda)\mathbf{1}_{l>\lambda}R_{st} - (1-\lambda)R_{st}$$

The threshold for μ at which the bank defaults is

$$\gamma_r = \frac{R_{st}(1 - \lambda - (l-\lambda)\mathbf{1}_{l>\lambda})}{2\left(1 - l - \frac{\lambda - l}{\delta p}\mathbf{1}_{\lambda>l}\right)}$$

Similarly, the threshold corresponding to the case where the bank invests in safe assets is

$$\gamma_s = \frac{R_{st}(1-\lambda-(l-\lambda)\mathbf{1}_{l>\lambda})}{1-l-\frac{\lambda-l}{p}\mathbf{1}_{\lambda>l}}$$

Whether or not liquidity stress causes the bank to default is inversely related to γ_i. If $l > \lambda$, then $\frac{d\gamma_i}{dl} = 0$ for $i = r, s$. If $\lambda \geq l$, then the assumption $p < 1$ (which also implies $\delta p < p < 1$) implies

$$\frac{d\gamma_r}{dl} = -\frac{R_{st}(1-\lambda)}{2\left(1-l-\frac{\lambda-l}{\delta p}\right)^2}\left(\frac{1}{\delta p}-1\right) < 0$$
$$\frac{d\gamma_s}{dl} = -\frac{R_{st}(1-\lambda)}{\left(1-l-\frac{\lambda-l}{p}\right)^2}\left(\frac{1}{p}-1\right) < 0$$

B.3 Proof of Lemma 1

Lemma 1. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$ and invests in risky assets if $\mu < \mu^*$.*

Determining conditions under which the bank experiences a run or defaults
The proof uses the default thresholds ζ_i and γ_i defined in the proof of Proposition 2.

The rest of the proof considers cases corresponding to the solvency of the bank after investing in either type of asset. In each case, we derive a threshold in the expected return μ^* such that it invests in safe assets if $\mu > \mu^*$ and invests in risky assets if $\mu < \mu^*$. In enumerating the cases, note that $\zeta_s < \zeta_r$, which illustrates that if liquidity stress causes a invested in safe assets to default in period 1 then it also causes a bank invested in risky assets to default in period 1. Note also that if $l > \lambda$ then $l > \zeta_i$ and $\mu > \gamma_i$ for $i = r, s$,[20] which illustrates that a bank cannot default from liquidity stress if it can pay all the early depositors using its liquid assets. The cases are therefore as follows.

Case 1: liquidity stress causes the bank to default if it invests in either type of asset
This case occurs when liquidity stress causes the bank to default in period 1 with either type of asset ($l < \zeta_s, \zeta_r$), liquidity stress causes the bank to default in period 1 if it invests in risky assets and to default in period 2 if it invests in safe assets ($\zeta_s < l < \zeta_r$ and $\mu < \gamma_s$), or liquidity stress causes a bank to default in period 2 if it invests in either type of asset ($\zeta_s, \zeta_r < l$ and $\mu < \gamma_s, \gamma_r$).

[20] In particular, note that the baseline assumptions in Section 3.1 imply $\mu > R_{st}$, and it's straightforward to show that in this case we have $\gamma_r = \frac{R_{st}}{2}$ and $\gamma_s = R_{st}$.

The expected value from investing in either type of asset can be written as

$$V_r^d = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{st} - R_{st}]$$
$$V_s^d = (1-q)[\mu(1-l) + lR_{st} - R_{st}]$$

Note that the two types of assets generate the same expected return but risky assets have a lower expected cost due to limited liability.

Define the relative value of risky assets by $\Delta V^{d,d} \equiv V_r^d - V_s^d$. Then

$$\Delta V = \frac{1}{2}(1-q)[R_{st} - lR_{st}] > 0$$

The fact that $\Delta V^{d,d}$ is positive in case 1 implies that the bank prefers risky assets for all values of μ, which implies $\mu^* = \infty$. The intuition is that risky assets achieve a higher net return in normal times since they generate the same expected return but have a lower cost due to limited liability.

Case 2: liquidity stress causes the bank to default only if it invests in safe assets

This case occurs when $\zeta_s, \zeta_r < l$ and $\gamma_r < \mu < \gamma_s$.

The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$V_r^s = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{st} - R_{st}] + \frac{1}{2}q\left[2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right) - (1-\lambda)R_{st}\right]$$
$$V_s^d = (1-q)[\mu(1-l) + lR_{st} - R_{st}]$$
$$\Delta V^{s,d} = \frac{1}{2}(1-q)[R_{st} - lR_{st}] + \frac{1}{2}q\left[2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right) - (1-\lambda)R_{st}\right] > 0$$

The fact that $\Delta V^{s,d}$ is positive in case 2 implies that the bank prefers risky assets for all values of μ, which implies $\mu^* = \infty$. This is because, as shown in case 1, risky assets always outperform in normal times, and in case 2 they also outperform in times of liquidity stress since only risk assets can generate a high enough return to potentially repay the late depositors.

Case 3: liquidity stress causes the bank to default only if it invests in risky assets

This case occurs when liquidity stress does not cause the bank to default if it invests in safe assets and but it does cause the bank to default if it invests in risky assets either in period 1 ($\zeta_s < l < \zeta_r$ and $\gamma_s < \mu$) or in period 2 ($\zeta_s, \zeta_r < l$ and $\gamma_s < \mu < \gamma_r$).

The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$V_r^d = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{st} - R_{st}]$$
$$V_s^s = (1-q)[\mu(1-l) + lR_{st} - R_{st}] + q\left[\mu\left(1 - l - \frac{\lambda - l}{p}\right) - (1-\lambda)R_{st}\right]$$
$$\Delta V^{d,s} = \frac{1}{2}(1-q)[R_{st} - lR_{st}] + q(1-\lambda)R_{st} - \mu q\left(1 - l - \frac{\lambda - l}{p}\right)$$

Note that $\Delta V^{d,s}$ is decreasing in μ, which reflects the fact that the bank can only acquire any fraction of the return in the liquidity stress state if it invests in safe assets. This determines the threshold μ^* for case 3 as

$$\mu^* = \frac{\frac{1}{2}(1-q)[R_{st} - lR_{st}] + q(1-\lambda)R_{st}}{q\left(1 - l - \frac{\lambda - l}{p}\right)}$$

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling on long-term debt markets

This case occurs when $\zeta_s, \zeta_r < l < \lambda$ and $\gamma_r, \gamma_s < \mu$. Note that the condition that the bank must sell on long-term debt markets to respond to liquidity stress implies $\lambda > l$.

The expected value from investing in either type of asset, the relative value of risky assets, and the propensity to take risk can be written as

$$V_r^s = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{st} - R_{st}] + \frac{1}{2}q\left[2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right) - (1-\lambda)R_{st}\right]$$
$$V_s^s = (1-q)[\mu(1-l) + lR_{st} - R_{st}] + q\left[\mu\left(1 - l - \frac{\lambda - l}{p}\right) - (1-\lambda)R_{st}\right]$$
$$\Delta V^{s,s} = \frac{1}{2}R_{st}\left[(1-q)(1-l) + q(1-\lambda)\right] - \mu q\frac{(1-\delta)(\lambda - l)}{p\delta}$$
$$\mu^* = \frac{\frac{1}{2}R_{st}\left[(1-q)(1-l) + q(1-\lambda)\right]}{\frac{q(1-\delta)(\lambda-l)}{p\delta}}$$

Case 5: the bank can respond to liquidity stress without selling on long-term debt markets

This case occurs when the bank has excess liquid assets or $\lambda < l$.

The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$
\begin{aligned}
V_r^e &= \frac{1}{2}(1-q)[2\mu(1-l)+lR_{st}-R_{st}]+\frac{1}{2}q[2\mu(1-l)+(l-\lambda)R_{st}-(1-\lambda)R_{st}] \\
V_s^e &= (1-q)[\mu(1-l)+lR_{st}-R_{st}]+q[\mu(1-l)+(l-\lambda)R_{st}-(1-\lambda)R_{st}] \\
\Delta V^{e,e} &= \frac{1}{2}(1-q)[R_{st}-lR_{st}]+\frac{1}{2}q[(1-\lambda)R_{st}-(l-\lambda)R_{st}]>0
\end{aligned}
$$

The fact that $\Delta V^{e,e}$ is positive in case 5 implies that the bank prefers risky assets for all values of μ, which implies $\mu^* = \infty$. This is because risky assets outperform in both normal times and times of liquidity stress since they generate the same expected return but have a lower cost due to limited liability. Since the bank does not have to sell on the long-term debt markets, the disadvantage of risky assets in the liquidity stress state due to having a lower price is completely avoided.

B.4 Proof of Proposition 3

Proposition 3. *There exists a threshold $l^*(p)$ such that μ^* is decreasing in l for $l < l^*(p)$ and μ^* is increasing in l for $l > l^*(p)$. The threshold $l^*(p)$ corresponds to the minimal level of liquidity at which the bank can survive liquidity stress if it invests in risky assets.*

Consider the effect of liquidity requirements l on the propensity to take risk μ^* when μ^* occurs in each of cases introduced in the proof of Lemma 1. Note that the cases depend on the thresholds ζ_i and γ_i, which are defined in the proof of Proposition 2.

Case 1: liquidity stress causes the bank to default if it invests in either type of asset ($l < \zeta_s, \zeta_r$, or $\zeta_s < l < \zeta_r$ and $\mu^* < \gamma_s$, or $\zeta_s, \zeta_r < l$ and $\mu^* < \gamma_s, \gamma_r$)

In this case, the bank always prefers risky assets and $\mu^* = \infty$.

Case 2: liquidity stress causes the bank to default only if it invests in safe assets ($\zeta_s, \zeta_r < l$ and $\gamma_r < \mu^* < \gamma_s$)

Note that case 2 requires $\gamma_r < \mu^* < \gamma_s$, but the proof of Lemma 1 shows that $\mu^* = \infty$ in case 2. Therefore μ^* never occurs in case 2.

Case 3: liquidity stress causes the bank to default only if it invests in risky assets ($\zeta_s < l < \zeta_r$ and $\gamma_s < \mu^*$, or $\zeta_s, \zeta_r < l$ and $\gamma_s < \mu^* < \gamma_r$)

Using the assumption that $p < 1$, in this case the effect of tightening liquidity requirements on the propensity to take risk is negative:

$$\frac{d\mu^*}{dl} = -\frac{\frac{1}{2}(1-q)R_{st}\left(1-l-\frac{\lambda-l}{p}\right)+\left(\frac{1}{p}-1\right)\left[\frac{1}{2}(1-q)[R_{st}-lR_{st}]+q(1-\lambda)R_{st}\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2} < 0$$

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling on long-term debt markets ($\zeta_s, \zeta_r < l < \lambda$ and $\gamma_r, \gamma_s < \mu^*$)
In this case, the effect of tightening liquidity requirements on the propensity to take risk is positive:

$$\frac{d\mu^*}{dl} = \frac{\frac{1}{2}R_{st}(1-\lambda)}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} > 0$$

Case 5: the bank can respond to liquidity stress without selling on long-term debt markets ($\lambda < l$)
In this case, the bank always prefers risky assets and $\mu^* = \infty$.

Summary
If l is low enough such that case 1 occurs, then $\mu^* = \infty$. By Proposition 2, the probability that liquidity stress causes the bank to default decreases in l. Thus, as l increases, μ^* eventually occurs in case 3, in which case $\frac{d\mu^*}{dl} < 0$. As l increases further, μ^* eventually occurs in case 4, in which case $\frac{d\mu^*}{dl} > 0$. As l increases further such that case 5 occurs, then $\mu^* = \infty$. Therefore $l^*(p)$ is the threshold between case 3 and case 4, which can also be written as the solution to $\mu^*(l;p) = \gamma_r(l;p)$.

B.5 Proof of Proposition 4

Proposition 4. *Increasing the price for long-term debt increases the range for l on which risk-taking increases in the tightness of liquidity requirements:* $\frac{dl^*(p)}{dp} < 0$.

Recall from the proof of Proposition 3 that $l^*(p)$ is the solution to $\mu^*(l,p) = \gamma_r(l,p)$. Let

$$F(l,p) \equiv \mu^*(l,p) - \gamma_r(l,p)$$

Consider μ^* as computed in case 4. By Proposition 3 we have $\frac{d\mu^*}{dl} > 0$, and by Proposition 2 we have $\frac{d\gamma_r}{dl} < 0$, which together imply $\frac{dF}{dl} > 0$. It is also straightforward to check that $\frac{d\mu^*}{dp} > 0$ and $\frac{d\gamma_r}{dp} < 0$ and therefore $\frac{dF}{dp} > 0$. By the implicit function theorem, we have

$$\frac{dl^*(p)}{dp} = -\frac{dF/dp}{dF/dl} < 0$$

B.6 Proof of Proposition 5

Proposition 5. *The optimal level of liquidity that minimizes the government's expenditure, denoted by l^G, is at least as great as the level $l^*(p)$ that minimizes the fraction of banks that invest in risky assets.*

We first compute the government's expected insurance payout G assuming there is an individual bank with expected return μ. Note that the total payout for depositors is given by $T = (1-\lambda q)R_{st} + q\lambda$. If the expected payout from banks is equal to B, then the government must pay the difference $G = T - B$. We compute government expenditure G for a set of cases depending on l and μ that correspond to the ones introduced in the proof of Lemma 1. Note that the cases depend on the thresholds ζ_i and γ_i, which are defined in the proof of Proposition 2.

Case 1: liquidity stress causes the bank to default if it invests in either type of asset
There are three subcases depending on whether liquidity stress causes a bank invested in either type of asset to default in period 1 or period 2. In the subcases below, the bank always prefers risky assets. Therefore, it suffices to compute the government expenditure assuming the bank chooses risky assets.

Case 1A: liquidity stress causes the bank to default in period 1 with either type of asset ($l < \zeta_s, \zeta_r$)
In this case, for a bank invested in risky assets the expected repayment to depositors is

$$B_{D1} = \frac{1}{2}(1-q)R_{st} + q[l + \delta p(1-l)]$$

Then denote the government's expenditure in this case by

$$G_{D1} = T - B_{D1} = (1-\lambda q)R_{st} + q\lambda - \left[\frac{1}{2}(1-q)R_{st} + q[l + \delta p(1-l)]\right]$$

Case 1B: liquidity stress causes the bank to default in period 1 if it invests in risky assets and to default in period 2 if it invests in safe assets ($\zeta_s < l < \zeta_r$ and $\mu < \gamma_s$)
In this case, the bank invests in risky assets and the associated government expenditure is G_{D1}.

Case 1C: liquidity stress causes a bank to default in period 2 if it invests in either type of asset ($\zeta_s, \zeta_r < l$ and $\mu < \gamma_s, \gamma_r$)

In this case, for a bank invested in risky assets the expected repayment to depositors is

$$B_{D2} = \frac{1}{2}(1-q)R_{st} + q\lambda + \frac{1}{2}q2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right)$$

Then denote the government's expenditure in this case by

$$G_{D2} = T - B_{D2} = (1-\lambda q)R_{st} + q\lambda - \left[\frac{1}{2}(1-q)R_{st} + q\lambda + \frac{1}{2}q2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right)\right]$$

Case 2: liquidity stress causes the bank to default only if it invests in safe assets ($\zeta_s, \zeta_r < l$ and $\gamma_r < \mu < \gamma_s$)

In this case, the bank always prefers risky assets. Therefore, it suffices to compute the government expenditure assuming the bank chooses risky assets. Assuming the bank can remain solvent in the face of liquidity stress if it invests in risky assets, the expected repayment to depositors is

$$B_{ND} = \frac{1}{2}(1-q)R_{st} + \frac{1}{2}q(1-\lambda)R_{st} + q\lambda$$

Denote the government's expenditure in this case by

$$G_{ND} = T - B_{ND} = (1-\lambda q)R_{st} + q\lambda - \left[\frac{1}{2}(1-q)R_{st} + \frac{1}{2}q(1-\lambda)R_{st} + q\lambda\right]$$

Case 3: liquidity stress causes the bank to default only if it invests in risky assets

There are two subcases depending on whether liquidity stress causes a bank invested in risky assets to default in period 1 or period 2. In either subcase, the bank prefers safe assets if $\mu > \mu^*$ and prefers risky assets if $\mu < \mu^*$, where μ^* is computed in the proof of Lemma 1. If the bank invests in safe assets and can remain solvent in the face of liquidity stress, then the expected repayment to depositors is equal to T and government expenditure is equal to zero. The government expenditure for a bank choosing risky assets depends on the subcase.

Case 3A: liquidity stress causes the bank to default in period 1 if it invests in risky assets ($\zeta_s < l < \zeta_r$ and $\gamma_s < \mu$)

By similar reasoning as in Case 1A, the government expenditure assuming the bank invests in risky assets is given by G_{D1}.

Case 3B: liquidity stress causes the bank to default in period 2 if it invests in risky

assets ($\zeta_s, \zeta_r < l$ and $\gamma_s < \mu < \gamma_r$)
By similar reasoning as in Case 1B, the government expenditure assuming the bank invests in risky assets is given by G_{D2}.

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling on long-term debt markets ($\zeta_s, \zeta_r < l < \lambda$ and $\gamma_r, \gamma_s < \mu$)
In this case, the bank prefers safe assets if $\mu > \mu^*$ and prefers risky assets if $\mu < \mu^*$. As argued in Case 3, if the bank invests in safe assets, then government expenditure is equal to zero. If the bank invests in risky assets and can remain solvent in the face of liquidity stress, then the expected government expenditure is equal to G_{ND}.

Case 5: the bank can respond to liquidity stress without selling on long-term debt markets ($\lambda < l$)
In this case, the bank always prefers risky assets. Since the bank can remain solvent in the face of liquidity stress, the expected government expenditure is equal to G_{ND}.

Aggregating over banks
Consider now that there is a mass of banks where the expected return is distributed according to the cdf F. We compute the government expenditure G averaged across the distribution of banks for a set of cases depending on l and the propensity to take risk μ^*.

- Case 1
  - Case 1A ($l < \zeta_s, \zeta_r$): $G = G_{D1}$
  - Case 1B ($\zeta_s < l < \zeta_r$ and $\mu^* < \gamma_s$): μ^* cannot occur in this case since being in Case 1 implies $\mu^* = \infty$
  - Case 1C ($\zeta_s, \zeta_r < l$ and $\mu^* < \gamma_s, \gamma_r$): μ^* cannot occur in this case since being in Case 1 implies $\mu^* = \infty$
- Case 2 ($\zeta_s, \zeta_r < l$ and $\gamma_r < \mu^* < \gamma_s$): μ^* cannot occur in this case since being in Case 2 implies $\mu^* = \infty$
- Case 3
  - Case 3A ($\zeta_s < l < \zeta_r$ and $\gamma_s < \mu^*$): $G = \int_{\mu_{min}}^{\mu^*} G_{D1} f(\mu) d\mu$
  - Case 3B ($\zeta_s, \zeta_r < l$ and $\gamma_s < \mu^* < \gamma_r$): $G = \int_{\mu_{min}}^{\mu^*} G_{D2} f(\mu) d\mu$
- Case 4 ($\zeta_s, \zeta_r < l < \lambda$ and $\gamma_r, \gamma_s < \mu^*$): $G = \int_{\mu_{min}}^{\gamma_r} G_{D2} f(\mu) d\mu + \int_{\gamma_r}^{\mu^*} G_{ND} f(\mu) d\mu$

- Case 5: $(\lambda < l)$: $G = G_{ND}$

Government's preferred liquidity level

It's straightforward to see that $G_{D1} \geq G_{D2}$ always holds. It's also clear that $G_{D2} \geq G_{ND}$ in cases where the government has to pay G_{D2}. Therefore the minimum government expenditure level occurs in either case 4 or case 5, which implies $l \geq l^*(p)$.

C Proofs for the extended model

C.1 Proof of Proposition 6

Proposition 6. *The bank never wants to hold more than the required level of liquid assets.*

Using similar notation as in the proof of Proposition 1, we have

$$\begin{aligned}
V_r^d &= \frac{1}{2}(1-q)[2\mu(1-l) + lR_{l,2} - R_{d,2}] \\
V_r^s &= \frac{1}{2}(1-q)[2\mu(1-l) + lR_{l,2} - R_{d,2}] \\
&\quad + \frac{1}{2}q\left[2\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l}\right) + (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} - (1-\lambda)R_{d,2}\right] \\
V_s^d &= (1-q)[\mu(1-l) + lR_{l,2} - R_{d,2}] \\
V_s^s &= (1-q)[\mu(1-l) + lR_{l,2} - R_{d,2}] \\
&\quad + q\left[\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l} + (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} - (1-\lambda)R_{d,2}\right]
\end{aligned}$$

By similar reasoning as in the proof of Proposition 1, we can see that the assumptions

$qR_{l,1} < \delta p$, $p < R_{l,1}$, and $\mu > \max\left\{\frac{1-q}{1-\frac{R_{l,1}q}{p}}R_{l,2}, \frac{1}{2}\frac{1-q}{1-\frac{R_{l,1}q}{\delta p}}R_{l,2}\right\}$ imply

$$\begin{aligned}
\frac{dV_r^d}{dl} &= \frac{1}{2}(1-q)[-2\mu + R_{l,2}] < 0 \\
\frac{dV_r^s}{dl} &= \frac{1}{2}(1-q)[-2\mu + R_{l,2}] - q\mu + q\mu\frac{R_{l,1}}{\delta p}\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l} + \frac{1}{2}qR_{l,2}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} \\
&= \left[-\mu\left(1 - \frac{qR_{l,1}}{\delta p}\right) + \frac{1}{2}(1-q)R_{l,2}\right]\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l} \\
&\quad + \frac{1}{2}[-2\mu + R_{l,2}]\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} < 0 \\
\frac{dV_s^d}{dl} &= (1-q)[-\mu + R_{l,2}] < 0 \\
\frac{dV_s^s}{dl} &= (1-q)[-\mu + R_{l,2}] - q\mu + q\mu\frac{R_{l,1}}{p}\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l} + qR_{l,2}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} \\
&= \left[-\mu\left(1 - \frac{qR_{l,1}}{p}\right) + (1-q)R_{l,2}\right]\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l} \\
&\quad + [-\mu + R_{l,2}]\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda} < 0
\end{aligned}$$

C.2 Proof of Proposition 7

Proposition 7. *Holding liquid assets reduces the probability that a liquidity shock causes the bank to default.*

Using similar notation as in the proof of Proposition 2, the thresholds determining whether liquidity stress causes a bank to default or not can be written as

$$\begin{aligned}
\zeta_r &= \frac{R_{d,1}\lambda - p\delta}{R_{l,1} - p\delta} \\
\zeta_s &= \frac{R_{d,1}\lambda - p}{R_{l,1} - p} \\
\gamma_r &= \frac{R_{d,2}(1-\lambda) - (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda}}{2\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l}\right)} \\
\gamma_s &= \frac{R_{d,2}(1-\lambda) - (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}}\mathbf{1}_{R_{l,1}l > R_{d,1}\lambda}}{1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{p}\mathbf{1}_{R_{d,1}\lambda > R_{l,1}l}}
\end{aligned}$$

Clearly, increasing l always reduces the probability of default in period 1. As for the period 2 default thresholds, if $R_{l,1}l \geq R_{d,1}\lambda$, then the assumptions $R_{l,1} \geq R_{d,1}$ and $R_{l,2} \geq$

$R_{d,2}$ implies[21]

$$\frac{d\gamma_r}{dl} = -\frac{(1-\lambda)(R_{l,2}-R_{d,2}) + \lambda\frac{R_{l,2}}{R_{l,1}}(R_{l,1}-R_{d,1})}{2(1-l)^2} \leq 0$$
$$\frac{d\gamma_s}{dl} = -\frac{(1-\lambda)(R_{l,2}-R_{d,2}) + \lambda\frac{R_{l,2}}{R_{l,1}}(R_{l,1}-R_{d,1})}{(1-l)^2} \leq 0$$

If $R_{l,1}l \leq R_{d,1}\lambda$, then the assumption $R_{l,1} > p$ (which also implies $R_{l,1} > p > \delta p$) implies

$$\frac{d\gamma_r}{dl} = -\frac{R_{d,2}(1-\lambda)}{2\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right)^2}\left(\frac{R_{l,1}}{\delta p}-1\right) < 0$$
$$\frac{d\gamma_s}{dl} = -\frac{R_{d,2}(1-\lambda)}{\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)^2}\left(\frac{R_{l,1}}{p}-1\right) < 0$$

C.3 Proof of Proposition 8

Proposition 8. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$ and invests in risky assets if $\mu < \mu^*$. Moreover, there is a threshold $l^*(p)$ such that μ^* is decreasing in l for $l < l^*(p)$ and μ^* is increasing in l for $l > l^*(p)$.*

The proof follows cases analogous to those introduced in the proof of Lemma 1. The proof uses the thresholds ζ_i and γ_i defined in the proof of Proposition 7.

Case 1: liquidity stress causes the bank to default if it invests in either type of asset ($l < \zeta_s, \zeta_r$, or $\zeta_s < l < \zeta_r$ and $\mu^* < \gamma_s$, or $\zeta_s, \zeta_r < l$ and $\mu^* < \gamma_s, \gamma_r$)
The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$V_r^d = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{l,2} - R_{d,2}]$$
$$V_s^d = (1-q)[\mu(1-l) + lR_{l,2} - R_{d,2}]$$
$$\Delta V^{d,d} = \frac{1}{2}(1-q)[R_{d,2} - lR_{l,2}] > 0$$

Note that the last inequality uses the assumption $R_{d,2} \geq lR_{l,2}$. The fact that $\Delta V^{d,d} > 0$ implies that risky assets are always preferred in this case, so $\mu^* = \infty$.

[21] One can also check using these assumptions that $\gamma_i \leq R_{l,2}$, and hence there is no risk of default since we have also assumed $\mu > R_{l,2}$.

Case 2: liquidity stress causes the bank to default only if it invests in safe assets ($\zeta_s, \zeta_r < l$ and $\gamma_r < \mu^* < \gamma_s$)
The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$
\begin{aligned}
V_r^s &= \frac{1}{2}(1-q)[2\mu(1-l)+lR_{l,2}-R_{d,2}] + \frac{1}{2}q\left[2\mu\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right)-(1-\lambda)R_{d,2}\right] \\
V_s^d &= (1-q)[\mu(1-l)+lR_{l,2}-R_{d,2}] \\
\Delta V^{s,d} &= \frac{1}{2}(1-q)[R_{d,2}-lR_{l,2}] + \frac{1}{2}q\left[2\mu\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right)-(1-\lambda)R_{d,2}\right] > 0
\end{aligned}
$$

Note that the last inequality uses the assumption $R_{d,2} \geq lR_{l,2}$. The fact that $\Delta V^{s,d} > 0$ implies that risky assets are always preferred in this case, so $\mu^* = \infty$.

Case 3: liquidity stress causes the bank to default only if it invests in risky assets ($\zeta_s < l < \zeta_r$ and $\gamma_s < \mu^*$, or $\zeta_s, \zeta_r < l$ and $\gamma_s < \mu^* < \gamma_r$)
The expected value from investing in either type of asset, the relative value of risky assets, and the propensity to take risk can be written as

$$
\begin{aligned}
V_r^d &= \frac{1}{2}(1-q)[2\mu(1-l)+lR_{l,2}-R_{d,2}] \\
V_s^s &= (1-q)[\mu(1-l)+lR_{l,2}-R_{d,2}] + q\left[\mu\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)-(1-\lambda)R_{d,2}\right] \\
\Delta V^{d,s} &= \frac{1}{2}(1-q)[R_{d,2}-lR_{l,2}] + q(1-\lambda)R_{d,2} - \mu q\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right) \\
\mu^* &= \frac{\frac{1}{2}(1-q)[R_{d,2}-lR_{l,2}] + q(1-\lambda)R_{d,2}}{q\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)}
\end{aligned}
$$

Using the assumptions $R_{l,1} > p$ and $R_{d,2} \geq lR_{l,2}$, we have that the effect of tightening liquidity requirements on the propensity to take risk is negative:

$$
\frac{d\mu^*}{dl} = -\frac{\frac{1}{2}(1-q)R_{l,2}\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)+\left(\frac{R_{l,1}}{p}-1\right)\left[\frac{1}{2}(1-q)[R_{d,2}-lR_{l,2}]+q(1-\lambda)R_{d,2}\right]}{q\left(1-l-\frac{R_{d,1}\lambda - R_{l,1}l}{p}\right)^2} < 0
$$

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling on long-term debt markets ($\zeta_s, \zeta_r < l < \frac{R_{d,1}}{R_{l,1}}\lambda$ **and** $\gamma_r, \gamma_s < \mu^*$)
The expected value from investing in either type of asset, the relative value of risky assets,

and the propensity to take risk can be written as

$$V_r^s = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{l,2} - R_{d,2}] + \frac{1}{2}q\left[2\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right) - (1-\lambda)R_{d,2}\right]$$

$$V_s^s = (1-q)[\mu(1-l) + lR_{l,2} - R_{d,2}] + q\left[\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{p}\right) - (1-\lambda)R_{d,2}\right]$$

$$\Delta V^{s,s} = \frac{1}{2}(1-q)(R_{d,2} - lR_{l,2}) + \frac{1}{2}q(1-\lambda)R_{d,2} - \mu q\frac{(1-\delta)(R_{d,1}\lambda - R_{l,1}l)}{p\delta}$$

$$\mu^* = \frac{1}{2}\frac{(1-q)(R_{d,2} - lR_{l,2}) + q(1-\lambda)R_{d,2}}{\frac{q(1-\delta)(R_{d,1}\lambda - R_{l,1}l)}{p\delta}}$$

In this case, under the assumption that $\frac{R_{d,2}}{R_{l,2}} \geq \frac{R_{d,1}}{R_{l,1}}$, the effect of tightening liquidity requirements on the propensity to take risk is positive:

$$\frac{d\mu^*}{dl} = \frac{1}{2}\frac{(1-q\lambda)R_{l,1}R_{d,2} - \lambda(1-q)R_{l,2}R_{d,1}}{\frac{q(1-\delta)\left(R_{d,1}\lambda - R_{l,1}l\right)^2}{p\delta}} > 0$$

Case 5: the bank can respond to liquidity stress without selling on long-term debt markets $\left(\frac{R_{d,1}}{R_{l,1}}\lambda < l\right)$

The expected value from investing in either type of asset and the relative value of risky assets can be written as

$$V_r^e = \frac{1}{2}(1-q)[2\mu(1-l) + lR_{l,2} - R_{d,2}] + \frac{1}{2}q\left[2\mu(1-l) + (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}} - (1-\lambda)R_{d,2}\right]$$

$$V_s^e = (1-q)[\mu(1-l) + lR_{l,2} - R_{d,2}] + q\left[\mu(1-l) + (R_{l,1}l - R_{d,1}\lambda)\frac{R_{l,2}}{R_{l,1}} - (1-\lambda)R_{d,2}\right]$$

$$\Delta V^{e,e} = \frac{1}{2}(1-q)[R_{d,2} - lR_{l,2}] + \frac{1}{2}q\left[(1-\lambda)(R_{d,2} - lR_{l,2}) + \lambda\frac{R_{l,2}}{R_{l,1}}(R_{d,1} - lR_{l,1})\right] > 0$$

Note that $\Delta V^{e,e} > 0$ follows from assuming $R_{d,2} \geq lR_{l,2}$ and $R_{d,1} \geq lR_{l,1}$. The fact that ΔV is positive implies that the bank always prefers risky assets in this case, so $\mu^* = \infty$.

Summary

The reasoning is similar to Proposition 3: $l^*(p)$ is the threshold between case 3 and case 4, which can also be written as the solution to $\mu^*(l;p) = \gamma_r(l;p)$.

C.4 Proof of Proposition 10

Proposition 10. *The optimal level of liquidity that minimizes the government's expenditure, l^G, is at least as great as the level $l^*(p)$ that minimizes the fraction of banks that invest in risky assets.*

We follow the structure of the proof of Proposition 5. It's straightforward to check that the government's expenditure in each case is the same function of G_{D1}, G_{D2}, and G_{ND} as in the proof of Proposition 5, except that we now have

$$G_{D1} = T - B_{D1} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda - \left[\frac{1}{2}(1-q)R_{d,2} + wq[R_{l,1}l + \delta p(1-l)]\right]$$
$$G_{D2} = T - B_{D2} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda - \left[\frac{1}{2}(1-q)R_{d,2} + q\lambda R_{d,1} + \frac{1}{2}wq2\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right)\right]$$
$$G_{ND} = T - B_{ND} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda - \left[\frac{1}{2}(1-q)R_{d,2} + \frac{1}{2}q(1-\lambda)R_{d,2} + q\lambda R_{d,1}\right]$$

It's straightforward to see that $G_{D1} \geq G_{D2}$ always holds. It's also clear that $G_{D2} \geq G_{ND}$ for cases in which the government pays G_{D2}. Therefore the minimum government expenditure level occurs in either case 4 or case 5, which implies $l \geq l^*(p)$.

D Tables

D.1 Reserve requirement tables

Table 1: Summary statistics for the reserve requirement exercise. This table presents summary statistics for the sample of bank-quarter observations obtained from the Call Reports during the period 1993Q1-2018Q4 and omitting banks for which the deviation between net transactions accounts and the low reserve tranche upper threshold exceeds 30%.

	N	Mean	SD	P25	P75
Marginal RR (%)	64564	5.90	3.45	3.00	10.00
Log assets	64564	12.73	0.75	12.14	13.16
Equity/assets (%) (C)	64564	9.77	3.12	7.93	10.88
NPLs/loans (%) (A)	64564	1.36	1.90	0.32	1.60
Non-interest expenses/assets (%) (M)	64564	1.07	0.65	0.73	1.23
Net income/assets (%) (E)	64564	1.01	1.01	0.71	1.43
Reserves/assets (%) (L)	64564	18.65	45.90	4.35	14.95
Sensitivity to market risk (%) (S)	64564	14.55	9.18	6.60	21.19

Table 2: The effect of the reserve requirement on the reserves to NTA ratio. This table presents results from estimating variations of the regression $Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \gamma controls_{it-1} + \phi_t + \epsilon_{it}$ where Y_{it} is the reserves to NTA ratio for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's net transaction accounts and low reserve tranche upper threshold, D_{it} indicates whether a bank's net transaction accounts exceeded the threshold, $controls_{it-1}$ is a set of lagged controls that includes bank size and proxies for indicators from the CAMELS risk rating system (as described in Section 4.2) excluding the dependent variable, and ϕ_t represents time fixed effects. T-statistics computed using bank-clustered standard errors are reported in parentheses. The specification is estimated on a subset of banks exhibiting a deviation from the low reserve tranche threshold that is less than 30%. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) reports $\delta/(10-3)$ when estimating the regression on the full sample period without the controls and time fixed effects, column (2) includes the controls and fixed effects, and columns (3) and (4) report the corresponding results from on a subsample restricting to years before 2008.

	(1) Base	(2) + ctrls + FE	(3) pre-2008	(4) + ctrls + FE
RKD estimate	0.016**	0.029***	0.003*	0.005***
	(2.07)	(4.01)	(1.82)	(3.25)
Observations	64564	64564	42633	42633
R^2	0.000	0.263	0.000	0.244
Controls	No	Yes	No	Yes
Quarter FE	No	Yes	No	Yes

Table 3: The effect of the reserve requirement on the non-performing loans ratio. This table presents results from estimating variations of the regression $Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \gamma controls_{it-1} + \phi_t + \epsilon_{it}$ where Y_{it} is the non-performing loans ratio for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's net transaction accounts and low reserve tranche upper threshold, D_{it} indicates whether a bank's net transaction accounts exceeded the threshold, $controls_{it-1}$ is a set of lagged controls that includes bank size and proxies for indicators from the CAMELS risk rating system (as described in Section 4.2) excluding the dependent variable, and ϕ_t represents time fixed effects. T-statistics computed using bank-clustered standard errors are reported in parentheses. The specification is estimated on a subset of banks exhibiting a deviation from the low reserve tranche threshold that is less than 30%. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) reports $\delta/(10-3)$ when estimating the regression on the full sample period without the controls and time fixed effects, column (2) includes the controls and fixed effects, and columns (3) and (4) report the corresponding results from on a subsample restricting to years before 2008.

	(1)	(2)	(3)	(4)
	Base	+ ctrls + FE	pre-2008	+ ctrls + FE
RKD estimate	0.000	-0.000	0.000	0.000
	(0.39)	(-0.09)	(0.18)	(0.02)
Observations	64564	61780	42633	40844
R^2	0.000	0.318	0.001	0.121
Controls	No	Yes	No	Yes
Quarter FE	No	Yes	No	Yes

D.2 Liquidity coverage ratio tables

Table 4: Summary statistics.

	N	Mean	SD	P25	P75
LCR indicator	10243	0.11	0.31	0.00	0.00
Log assets	10243	15.42	1.56	14.40	16.07
Tier 1 capital/assets (%) (C)	10243	9.80	2.63	8.43	10.54
NPLs/loans (%) (A)	10243	1.81	2.15	0.58	2.15
Non-interest expenses/assets (%) (M)	10243	1.05	0.78	0.72	1.12
Net income/assets (%) (E)	10243	0.92	0.93	0.65	1.20
Total liquid assets/assets (%) (L)	10243	17.78	9.80	10.90	22.10
Sensitivity to market risk (%) (S)	10243	5.50	6.35	1.60	6.84

Table 5: Comparison of observables. This table presents the means of characteristics for bank holding companies (BHCs) that were subject to the 100% LCR or the 70% LCR compared to banks that were exempt from the LCR during the period 2010Q1-2013Q2. It also presents the t-statistic for the coefficient η from estimating the regression $Y_{it} = \eta LCR_i + \phi_t + \epsilon_{it}$ and computing bank-clustered standard errors for each characteristic Y_{it}.

	LCR-exempt	LCR	T-statistic
Log assets	14.83	18.82	32.157
Tier 1 capital/assets	9.715	8.395	-3.233
NPLs/loans	2.851	3.309	1.289
Non-interest expenses/assets	1.087	1.407	1.79
Net income/assets	0.717	0.706	-.095
Liquid assets/assets	19.22	20.66	.607
Sensitivity to market risk	5.918	8.775	1.757

Table 6: Effect of liquidity coverage ratio on the liquidity ratio. This table presents results from estimating the regression $Y_{it} = \beta LCR_i \times post2013Q3_t + \gamma controls_{it-1} + \psi_i + \phi_t + \epsilon_{it}$ where Y_{it} is the liquidity ratio, LCR_i is an indicator for whether a bank was subject to either the 100% LCR or the 70% LCR (Column (1)), only the 100% LCR (Column (2)), or only the 70% LCR (Column (3)) as of the implementation date of 2015Q1, $post2013Q3_t$ is an indicator for quarters greater than or equal to 2013Q3, $controls_{it-1}$ is a set of controls that includes bank size and indicators from the CAMELS risk rating system (as described in section 5.3) excluding the dependent variable, ψ_i represent bank fixed effects, ϕ_t represent time fixed effects. Column (3) excludes banks subject to the 100% LCR. T-statistics computed using bank-clustered standard errors are reported in parentheses. T-statistics with standard errors are clustered by bank. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level.

	(1) Either LCR	(2) 100% LCR	(3) 70% LCR
LCR x Post	3.402***	4.422***	2.446***
	(4.70)	(3.77)	(3.37)
Observations	10237	10237	9747
R^2	0.863	0.863	0.837
Controls	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes

Table 7: Effect of liquidity coverage ratio on the non-performing loans ratio. This table presents results from estimating the regression $Y_{it} = \beta LCR_i \times post2013Q3_t + \gamma controls_{it-1} + \psi_i + \phi_t + \epsilon_{it}$ where Y_{it} is the non-performing loans ratio, LCR_i is an indicator for whether a bank was subject to either the 100% LCR or the 70% LCR (Column (1)), only the 100% LCR (Column (2)), or only the 70% LCR (Column (3)) as of the implementation date of 2015Q1, $post2013Q3_t$ is an indicator for quarters greater than or equal to 2013Q3, $controls_{it-1}$ is a set of controls that includes bank size and indicators from the CAMELS risk rating system (as described in section 5.3) excluding the dependent variable, ψ_i represent bank fixed effects, ϕ_t represent time fixed effects. Column (3) excludes banks subject to the 100% LCR. T-statistics computed using bank-clustered standard errors are reported in parentheses. T-statistics with standard errors are clustered by bank. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level.

	(1) Either LCR	(2) 100% LCR	(3) 70% LCR
LCR x Post	-0.181	-0.369	-0.043
	(-0.60)	(-0.61)	(-0.23)
Observations	10237	10237	9747
R^2	0.695	0.695	0.697
Controls	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes

Table 8: Effect of liquidity coverage ratio on the CDS spread. This table presents results from estimating the regression $Y_{it} = Post_t + \beta LCR_i \times Post_t + \psi_i + \epsilon_{it}$ where Y_{it} is the difference between the maximum and the minimum of the CDS spread in period t, LCR_i is an indicator for whether a bank was subject to the 100% LCR as of the implementation date of 2015Q1, $Post_t$ is an indicator that equals 1 for the COVID-19 crisis (dates in 2020) and 0 for the global financial crisis (dates in 2007-2009), ψ_i represent bank fixed effects. T-statistics computed using bank-clustered standard errors are reported in parentheses. T-statistics with standard errors are clustered by bank. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level.

	(1) 100% LCR
LCR x Post	1193.293
	(1.44)
Observations	16
R^2	0.809
Bank FE	Yes

E Omitted figures

Figure 10: The effect of the reserve requirement on the non-performing loans ratio. This figure presents a binned scatterplot relating the non-performing loans ratio to the percentage of net transaction accounts to the low reserve tranche threshold for observations within a 30% deviation of the low reserve tranche threshold. The figure also presents predicted values from estimating the following specification: $Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \epsilon_{it}$, where Y_{it} is the dependent variable for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's net transaction accounts and low reserve tranche upper threshold, and D_{it} indicates whether a bank's net transaction accounts exceeded the threshold.

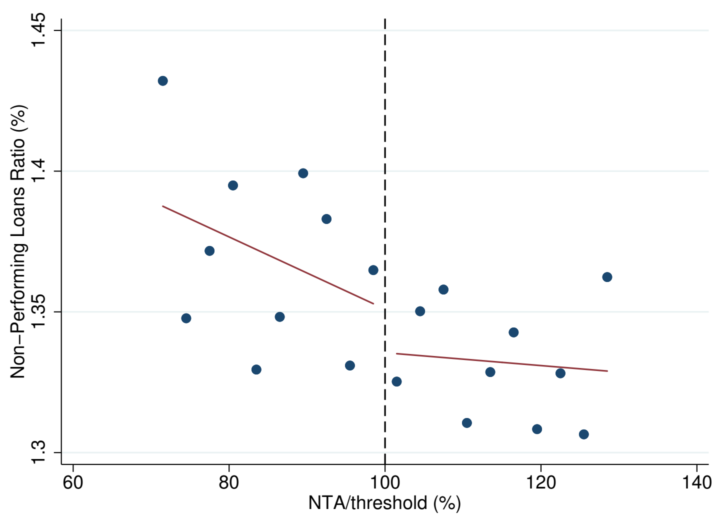
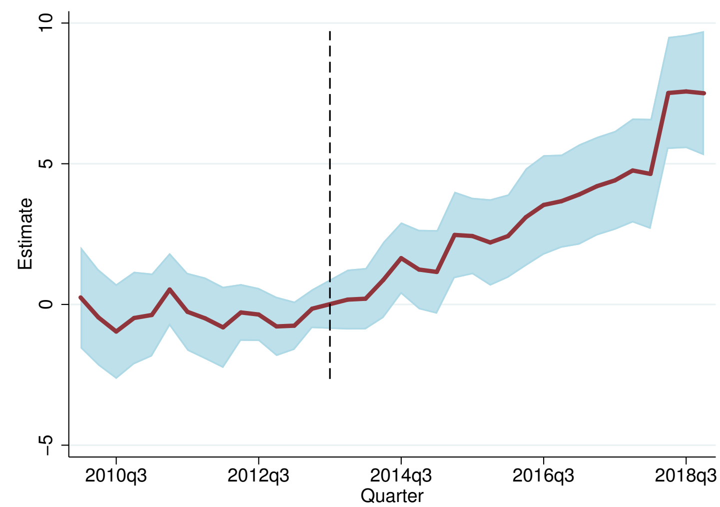
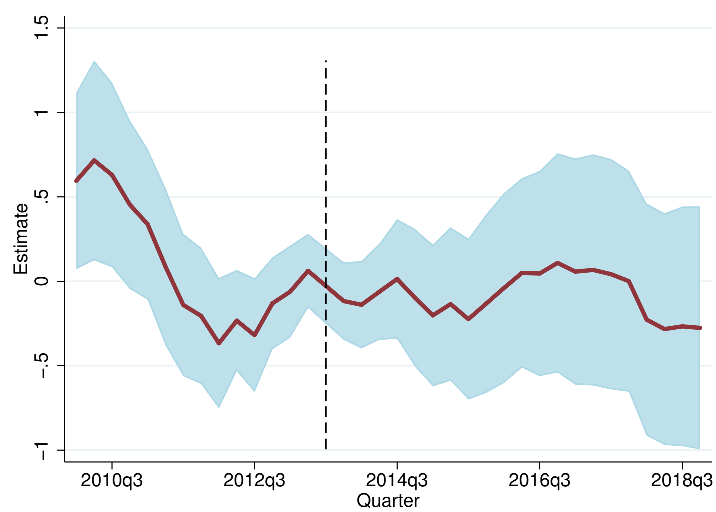


Figure 11: The effect of the liquidity ratio (quarterly effects). This figure presents the coefficients β_t from estimating the regression $\Delta Y_{it} = \sum_{t \neq 2013Q4} \beta_t LCR_i \times \phi_t + \gamma controls_{it-1} + \psi_i + \phi_t + \epsilon_{it}$ where Y_{it} is the dependent variable for bank i in quarter t, LCR_i is an indicator for whether a bank was subject to the 100% LCR or the 70% LCR at the implementation date of 2015Q1, $controls_{it-1}$ is a set of controls that includes bank size and indicators from the CAMELS risk rating system (as described in Section 4.2) excluding the dependent variable, ψ_i represents bank fixed effects, and ϕ_t represents time fixed effects. 95% confidence intervals are computed using bank-clustered standard errors. The dashed line indicates the LCR proposal date of 2013Q3.

(a) Liquidity ratio



(b) Non-performing loans

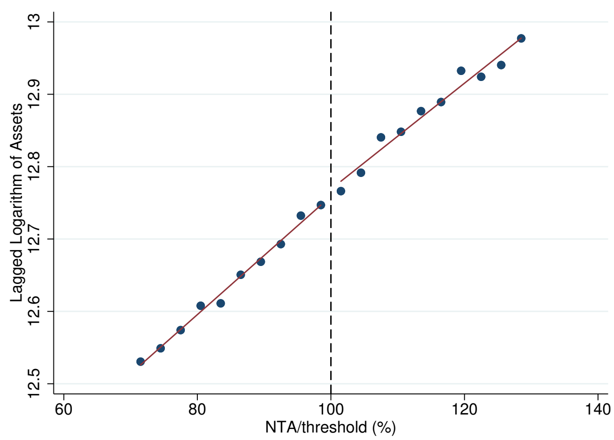


Online Appendix

F The reserve requirement and other bank characteristics

Figure 12: The effect of the reserve requirement on predetermined covariates. This figure presents a binned scatterplot relating the lag of each dependent variable to the percentage of net transaction accounts to the low reserve tranche threshold for observations within a 30% deviation of the low reserve tranche threshold. The figure also presents predicted values from estimating the following specification: $Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \epsilon_{it}$, where Y_{it} is the lag of a characteristic for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's net transaction accounts and low reserve tranche upper threshold, and D_{it} indicates whether a bank's net transaction accounts exceeded the threshold.

(a) Log assets



(b) Capital ratio

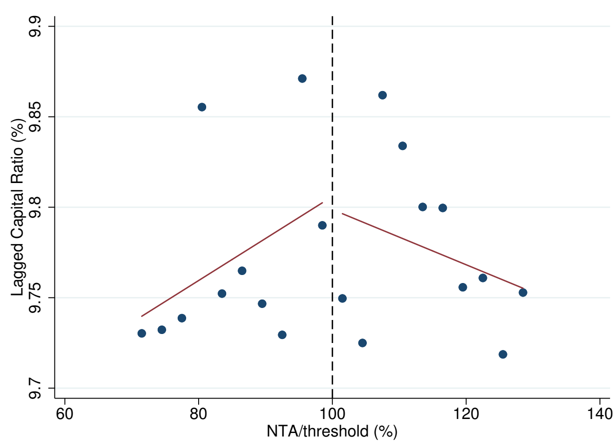
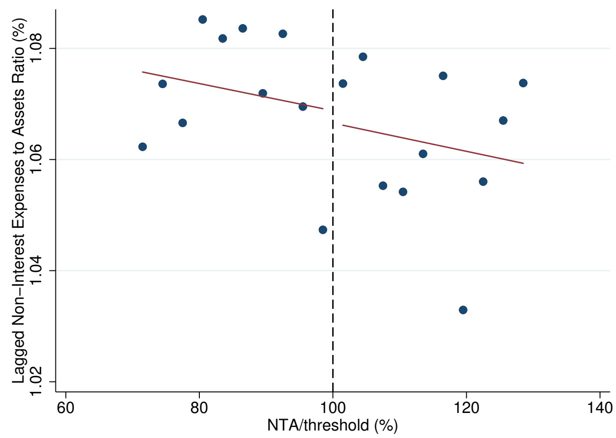
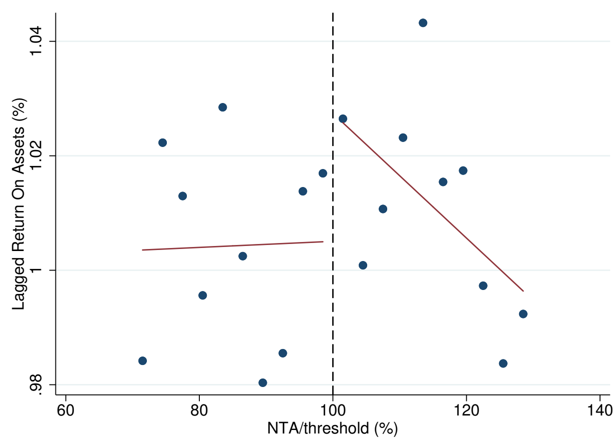


Figure 12: The effect of the reserve requirement (continued)

(c) Non-interest expense ratio



(d) Return on assets



(e) Sensitivity to market risk

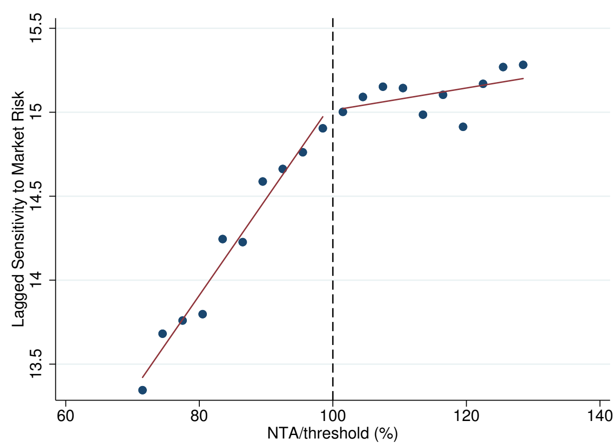


Table 9: The effect of reserve requirements on predetermined covariates. This table presents results from estimating variations of the regression $Y_{it} = \alpha \Delta NTA_{it} + \beta D_{it} + \delta(D_{it} * \Delta NTA_{it}) + \gamma controls_{it-1} + \phi_t + \epsilon_{it}$ where Y_{it} is the lag of the indicated dependent variable for bank i in year t, ΔNTA_{it} is the percentage deviation between a bank's net transaction accounts and low reserve tranche upper threshold, D_{it} indicates whether a bank's net transaction accounts exceeded the threshold. T-statistics computed using bank-clustered standard errors are reported in parentheses. The specification is estimated on a subset of banks exhibiting a deviation from the low reserve tranche threshold that is less than 30%. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Each column reports $\delta/(10-3)$.

	(1) Log assets	(2) Capital	(3) Expenses	(4) ROA	(5) Sensitivity
Treatment x (NTA - threshold)	-0.000	-0.001	-0.000	-0.000	-0.007***
	(-0.60)	(-0.79)	(-0.38)	(-0.79)	(-3.25)
Observations	64564	64564	64564	64564	64564
R^2	0.034	0.000	0.000	0.000	0.004
Controls	No	No	No	No	No
Quarter FE	No	No	No	No	No