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Liquidity Regulation and Bank Risk Taking on the Horizon

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Liquidity Regulation and Bank Risk Taking on the Horizon*

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Abstract

We examine how banks' liquidity requirements affect their incentives to take risk with their remaining illiquid assets. Our model predicts that banks with more stable liabilities are more likely to engage in risk taking in response to tighter liquidity requirements. This prediction is borne out in transaction-level data on corporate and mortgage loans for U.S. banks subject to the liquidity coverage ratio (LCR). For identification, we exploit variation in long-term bank bonds held by insurance companies that are not affected by the LCR. Our results point to a trade-off between bank risk taking and ensuring funding resilience over different horizons.

Keywords: liquidity regulation, bank risk taking, insurance sector, LCR, NSFR

JEL classification codes: G20, G21, G22, G28

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1 Introduction

Economists' efforts to understand banking crises are concentrated on mapping sources of financial fragility to banks' business models and balance sheets. Banks' maturity mismatch exposes them to liquidity and rollover risk, be it through bank runs or wholesale financiers' unwillingness to extend their funding. Creditors' and governments' policy responses to maturity mismatch further reinforce banks' excessive reliance on short-term borrowing (Farhi and Tirole, 2012; Brunnermeier and Oehmke, 2013; Segura and Suárez, 2017). Related to banks' maturity transformation is also the mismatch between the liquidity of banks' assets and their ability to raise funds by borrowing against their assets (Bai, Krishnamurthy and Weymuller, 2018). By governing banks' response to crises—e.g., fire sales—liquidity mismatch can give rise to pecuniary externalities and, thus, amplification effects (Brunnermeier, Gorton and Krishnamurthy, 2013; Brunnermeier and Krishnamurthy, 2014).

To address these perils, the post-crisis regulatory framework revised its liquidity requirements so as to promote resilience to short-term liquidity risk as well as funding stability over a longer time horizon. Liquidity regulations are at the same time designed with the objective in mind of mitigating default risk that could stem from banks' strategic liquidity management (e.g., Silva, 2019). However, little is known about whether the goals of ensuring funding resilience over the short and long run are conducive to, or actually pose a trade-off for, curbing banks' risk taking. To answer this question, we investigate whether liquidity regulations affect the incentive for banks to take risk with their remaining illiquid assets, and to what extent this depends on banks' funding stability. Building on a model that links liquidity risk with credit risk, we hypothesize that banks' share of stable liabilities determines their risk-taking response to tighter liquidity requirements. Using bank-level and transaction-level data, in conjunction with fluctuations in institutional investors' demand for long-term bank bonds, we test this prediction empirically. We find that banks with more stable funding are relatively more likely to engage in risk taking in response to tighter liquidity requirements.

In particular, we consider the introduction of the liquidity coverage ratio (LCR), which has been effective in the U.S. since January 2015, as a shock to banks' liquidity requirements. 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. As such, the LCR is designed to bolster the short-term resilience of banks' funding profile. Complementary to the LCR is the net stable funding ratio (NSFR). Its objective is to reduce funding risk arising from banks' maturity mismatch by requiring them to have a sufficient amount of stable funding relative to the liquidity and maturity of their assets. The final rule is effective in the U.S. as of July 2021.

To capture the interaction between liquidity requirements and banks' funding stability well before that date, we use heterogeneity in the share of banks' total liabilities held by insurance companies in the form of bank bonds. Insurance companies are at the center of fixed-income markets, and their aggregate holdings of bank bonds account for up to one-sixth of U.S. banks' total long-term funding. Bond holdings of insurance companies, insofar as they reflect the latter's demand, can affect the pricing of banks' long-term debt (Koijen and Yogo, 2019) and the latter's resilience during crises (Coppola, 2022), which can in turn determine banks' ability to access or maintain long-term funding. As such, a higher degree of long-term funding is associated with lower liquidity risk.[1] The LCR does not apply to insurers, isolating them from its direct impact. Since insurers' investment strategies focus on bond issuers' default risk rather than liquidity risk, and due to insurers' stable funding from selling insurance (Chodorow-Reich, Ghent and Haddad, 2021), their holdings of long-term bank bonds constitute a source of plausibly exogenous variation in banks' funding stability.

[1] Brunnermeier (2009) describes how an inability to roll over short-term debt contributed to failures during the financial crisis. Analogously to the reflection of liquidity risk in corporate spreads (Gopalan, Song and Yerramilli, 2014; Chen, Xu and Yang, 2021), Du and Palia (2018) document that short-term debt was associated with greater bank risk in the pre-crisis period, with a one-standard-deviation increase in short-term repo financing being associated with a 35 basis point higher stock-return volatility.

We start out by documenting two facts about how banks directly adjusted their balance sheets to comply with the LCR. We use quarterly balance-sheet data for bank holding companies (BHCs) from Compustat Bank, and estimate the effect of the LCR using a difference-in-differences specification based on the fact that the LCR only applies to BHCs with sufficiently high total assets or foreign exposures. First, we find that banks primarily adjusted to the LCR by decreasing illiquid assets rather than by increasing liquid assets, resulting in a contraction of balance-sheet size relative to banks exempt from the LCR. This is robust to using a smaller sample of banks that are more comparable in terms of their size.

Second, we examine how the effect of the LCR varies with the degree to which banks are exposed to liquidity risk stemming from their maturity mismatch, measured inversely by the fraction of liabilities consisting of stable funding such as long-term debt. We use data from the National Association of Insurance Commissioners (NAIC) to specifically focus on the fraction of liabilities consisting of bonds held by insurance companies. In this manner, we find that banks with more long-term funding supplied by the insurance sector increase their liquid-asset ratio relatively less in response to the LCR. To the extent that the NSFR is less likely to be binding for the latter group of banks, our finding speaks to the LCR and NSFR being potential complements, rather than substitutes as conjectured by Cecchetti and Kashyap (2018), who using a simplified version of a bank's balance sheet argue that the two types of requirements will typically not bind at the same time.

Motivated by these findings, we introduce a model to illustrate channels by which liquidity regulations can either increase or decrease the incentive for banks to take risk with their remaining illiquid assets. In the model, a risk-neutral bank acquires funding from investors, maintains a required fraction of liquid assets, such as those classified as high-quality liquid assets under the LCR, and chooses the risk of its remaining long-term assets, such as loans. Before the long-term assets mature, the bank may experience liquidity stress, which means that some investors withdraw their funds. The bank can respond to liquidity stress by either paying out of its liquid-asset stock or, if necessary, by selling its long-term assets 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. On the other hand, risky assets sell at a lower price, 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 shows that the effect of tighter liquidity requirements on the bank's incentive to invest in risky long-term assets qualitatively depends on its exposure to liquidity stress. For example, the bank has a high exposure to liquidity stress if it has a large fraction of unstable funding, such as short-term liabilities that could potentially be withdrawn before its assets mature. 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, as they can be liquidated at a higher price compared to risky assets. Tighter liquidity requirements improve the bank's profitability in states where it faces liquidity stress but does not default. They therefore increase the profitability of safe 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 low exposure to liquidity stress if it has a large fraction of stable funding, e.g., long-term liabilities such as bank bonds. In that case, the bank can adequately respond to liquidity stress without defaulting, even if it invests in risky long-term assets. Tightening liquidity regulations decreases the extent to which the bank needs to sell its long-term assets to respond to liquidity stress. This in turn mitigates the relative disadvantage of investing in risky assets, which is their lower liquidation price. Hence, tightening liquidity regulations increases the incentive to invest in risky assets. These results are robust to various extensions related to the returns of the bank's assets, the payment to investors, the definition of liquidity regulation, the choice space and costs associated with risky assets, and the effect of liquid assets on the propensity of a liquidity shock.

Our empirical evidence that banks adjusted to the LCR by decreasing illiquid assets, rather than by increasing liquid assets, and that banks with more stable funding from insurance companies exhibited a relatively weaker reduction in the ratio of illiquid assets to total assets is consistent with our main theoretical conjecture insofar as illiquid assets tend to be riskier. However, our model can be interpreted as comparing LCR-affected banks with different degrees of reliance on long-term funding, while holding constant the liquidity composition of their asset side. This makes it possible to use granular, transaction-level data to test our key empirical prediction that LCR-affected banks with more stable funding engage in relatively greater risk taking, conditional on loans being made.

For this purpose, we use data on syndicated loans from DealScan. Consistent with the theory, we find that the liquidity coverage ratio is associated with riskier loan originations for banks with more stable funding, as measured by the fraction of liabilities consisting of long-term bonds held by the insurance sector. We characterize bank risk taking by the ex-ante risk of firms financed by (lead) banks in syndicated loans (similarly to, for example, Heider, Saidi and Schepens, 2019). We complement these results with additional analyses of HMDA mortgage-application data, allowing us to not only test for the external validity of our findings across different credit markets and loan recipients, but also to better control for loan demand. In this manner, we find that LCR-affected banks with more stable funding stemming from insurance companies' investment in bank bonds grant more mortgages to riskier borrowers, as measured by their loan-to-income ratio, and more mortgages whose credit risk cannot readily be transferred.

We conclude from these results that while the LCR can be effective in bolstering resilience to short-term liquidity risk, tighter liquidity requirements may give rise to risk taking if they target funding stability over a longer time horizon. This implies a trade-off in ensuring funding resilience over different horizons, with potential repercussions for financial stability especially if the social costs of credit risk outweigh the benefits of stable funding for banks.

Relation to literature. This paper contributes to the literature that analyzes the need for liquidity regulation, how to design it, and its system-wide effects. Some papers evaluate the effectiveness of liquidity buffers and liquidity requirements, also in comparison to other regulations, in fostering financial stability (Myers and Rajan, 1998; Stein, 2012). In the dynamic partial-equilibrium model of De Nicolò, Gamba and Lucchetta (2014), liquidity requirements reduce the amount of lending, efficiency, and welfare. However, the equilibrium level of bank risk taking, as reflected by the risk of the loans made, also crucially affects welfare.

We present a theoretical model that can rationalize such risk taking in response to tighter liquidity requirements, alongside supporting empirical evidence. As such, our paper addresses prior work on two important causes of bank failures. First, the liquidity risk associated with banks' maturity transformation 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 stream of expected profits (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.

By showing theoretically and empirically that the interaction of liquidity requirements and funding stability may translate to bank risk taking, our findings contribute to a discussion of the trade-offs associated with liquidity regulations. Perotti and Suárez (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) argue that liquidity regulations with a structure like the LCR can correct for inefficient investment in liquid assets owing to investors' incomplete information about a bank's resilience to liquidity stress. Allen and Gale (2017) survey the literature, and conclude that it has not converged on a paradigm for understanding the role of liquidity regulations.

The empirical branch of this literature focuses on the effects of liquidity requirements on banks' asset-side activities, primarily their lending behavior, also outside of the U.S. (e.g., Bonner and Eijffinger, 2016; Banerjee and Mio, 2018). In the U.S., Roberts, Sarkar and Shachar (2022) argue that the LCR was associated with reduced liquidity creation, while Sundaresan and Xiao (2022) provide evidence that it led to a migration of liquidity risks to non-LCR banks.

This paper's insights are also related to the literature on financial crises more generally. In this literature, crises are usually explained as being caused by either panics or weak fundamentals (Goldstein, 2012). The basic underlying idea is that decision-makers transmit shocks by changing their exposure to risks, e.g., bank runs associated with deteriorations in fundamentals (Jacklin and Bhattacharya, 1988; Allen and Gale, 1998) or self-fulfilling crises caused by panics or the information of bank investors (e.g., Bryant, 1980; Diamond and Dybvig, 1983; Ahnert and Kakhbod, 2018; Babus and Farboodi, 2021). 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 LCR affects a bank's attitude toward credit risk. In this respect, our paper is analogous to work that studies how banks shift their portfolios in response to capital requirements (e.g., Koehn and Santomero, 1980), taxation (e.g., Célérier, Kick and Ongena, 2020), restrictions on certain financial products (e.g., Di Maggio and Kermani, 2017; Di Maggio, Kermani and Korgaonkar, 2019), and the business cycle (e.g., Begenau, 2020; Malherbe, 2020).

Finally, we use insurance companies' holdings of long-term bank bonds as a source of variation in banks' funding stability that should be unaffected by the LCR. As such, our paper contributes to a fledgling literature that considers the consequences of the ever-growing interconnectedness between banks and the insurance sector. Existing work focuses on the asset-side impact for banks, e.g., how insurance companies' business may affect bank lending (Garmaise and Moskowitz, 2009; Sastry, 2022), or the fact that insurers and banks trade in the same asset classes (Timmer, 2018; Becker, Opp and Saidi, 2022). Our paper complements this view by revealing the importance of the link between insurance companies and banks on the latter's liability side.

2 The Effect of the Liquidity Coverage Ratio on Banks' Balance Sheets

To motivate our analysis of the effect of the liquidity coverage ratio (LCR) on bank risk taking, we first present some facts about how U.S. banks adjusted their balance sheets to comply with it. We implement a difference-in-differences design based on the introduction of the LCR for a subset of bank holding companies (BHCs) in 2015. We find that the LCR had the intended effect, and was associated with an increasing fraction of liquid assets to total assets. Banks primarily achieved this by decreasing illiquid assets rather than by increasing liquid assets, resulting in a contraction of balance-sheet size relative to banks that were exempt from the LCR. In order to assess the role of funding stability in the bank-level response to the LCR, we exploit variation in the investment in long-term bank bonds by U.S. insurance companies that, as non-banks, are not directly affected by the LCR.

2.1 Implementation of the Liquidity Coverage Ratio in the U.S.

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.

A strict version of the LCR requires BHCs with total assets exceeding \$250 billion or on-balance-sheet foreign exposures exceeding \$10 billion to hold HQLA relative to net cash outflows at a ratio of 100%. A reduced version of the LCR of 70% applies to BHCs with assets between \$50 billion and \$250 billion. The U.S. implementation of the LCR was proposed in October 2013 and phased in from January 2015 to January 2017.

2.2 Data

We use quarterly balance-sheet data for U.S. BHCs from Compustat Bank during the period from 2010Q1 until 2019Q4. We supplement this with data on the universe of U.S. insurer holdings from the National Association of Insurance Commissioners (NAIC). We merge the end-of-year data from NAIC to the year preceding the current quarter in Compustat Bank. In particular, we use CUSIP-level end-of-year holdings from Schedule D Part 1, which covers insurer-specific holdings for all fixed-income securities (including Treasury bonds, corporate bonds, MBS, agency-backed RMBS, etc.), and focus on the stock of long-term bank bonds held by insurance companies, as measured by their book-adjusted carrying value (BACV). To link these holdings to the bond-issuing banks, we rely on the comprehensive Mergent FISD database and hand-match the names in the issuer field with the corresponding BHCs in Compustat Bank.

Table 1 presents summary statistics for various bank characteristics. The first set of variables corresponding to the primary explanatory variables includes an indicator for whether a bank met the criteria to be subject to either type of the LCR as of 2014Q4 (immediately before the implementation of the LCR) as well as the percentage of total liabilities consisting of long-term debt or bank bonds held by insurance companies (also conditional on being non-zero, showing a substantial extensive margin of banks receiving any funding from the insurance sector).

The second set of variables corresponding to the dependent variables includes liquid assets (which we approximate as cash, balances due from banks, and U.S. Treasury securities) to total assets, the logarithm of liquid assets, the logarithm of illiquid assets, and the logarithm of total assets.

The third set of variables corresponding to the controls includes characteristics corresponding to the CAMELS bank-risk rating system, except for liquidity since it is already included. This includes the ratio of Tier 1 capital to risk-weighted assets, the ratio of non-performing assets to loans net of provisions for losses as a measure of asset quality, the ratio of non-interest expenses to assets as a measure of managerial efficiency, the annualized return on assets as a measure of earnings, and the absolute difference between short-term assets and short-term liabilities as a measure of sensitivity to market risk.[2] We also control for the average maturity of a given bank's outstanding bonds.

2.3 Empirical Strategy

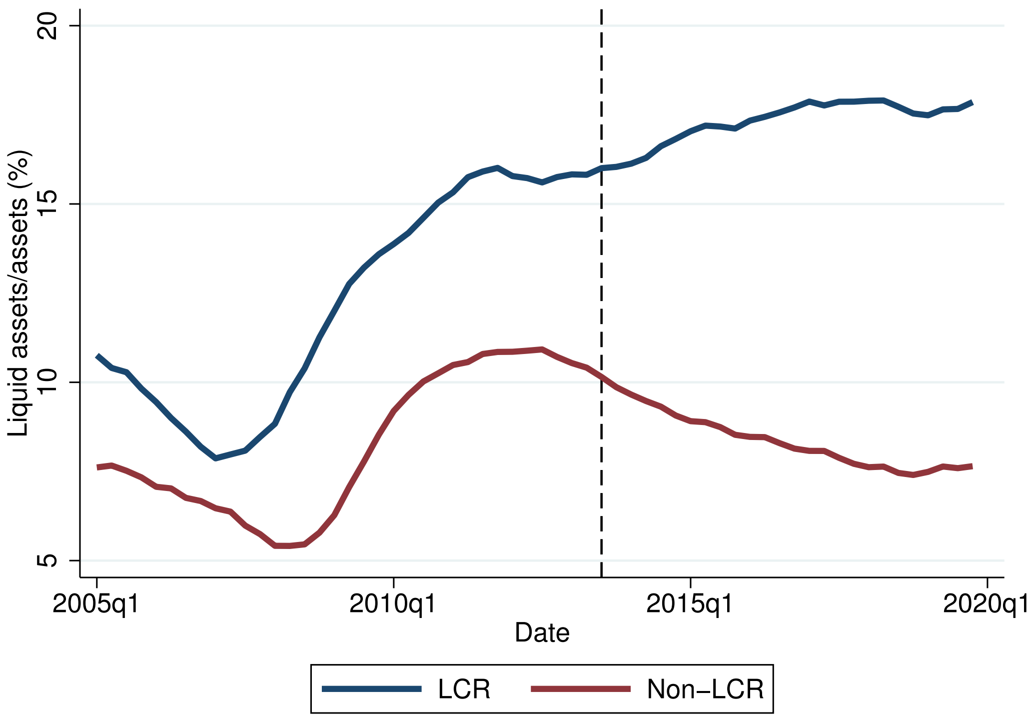
We assess how banks adjusted their balance sheets to accommodate the LCR by estimating the following baseline specification:

$$Y_{it} = \beta LCR_i \times Post_t + \gamma \mathbf{X}_{it-1} + \psi_i + \phi_t + \epsilon_{it}, \quad (1)$$

[2] In the measure of sensitivity to market risk, short-term assets include cash, balances due from banks, federal funds sold, and securities purchased under agreements to resell, whereas short-term liabilities include deposits, federal funds purchased, and securities sold under agreements to resell.

Figure 1: The Effect of the Liquidity Coverage Ratio on Liquid-asset Holdings

This figure shows the mean ratio of liquid assets (cash, balances due from banks, and U.S. Treasury securities) to total assets for bank holding companies that were subject to the liquidity coverage ratio (LCR) versus 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 in 2013Q3.



where Y_{it} is the liquid-asset ratio in % (from 0 to 100) for bank i in quarter t, LCR_i is an indicator for whether bank i was subject to either the 100% or 70% LCR as of 2014Q4 (immediately before the implementation date), $Post_t$ is an indicator for quarters after the proposal date of 2013Q3, $\mathbf{X}_{it-1}$ is a set of lagged bank-level control variables, and ψ_i and ϕ_t denote bank and year-quarter fixed effects, respectively. 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. Standard errors are clustered at the bank level.

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. In support of the validity of this assumption, Figure 1 shows that the treated and untreated groups experienced parallel trends for the quarters leading up to the introduction of the LCR in 2013Q3.[3]

In Table 2, we compare the treatment and control groups with respect to several characteristics in the period before the introduction of the LCR. Differences in some of these characteristics follow naturally from the LCR eligibility criteria. For instance, LCR-affected banks are larger (in terms of their balance sheets, including all asset-related items). In addition, long-term funding in general and insurance companies' investment in bank bonds in particular do not play any role for banks that are not affected by the LCR, which is why we exploit this source of variation for the group of LCR-affected banks. While notable, these differences often reflect time-invariant characteristics of the two types of banks, which are captured by bank fixed effects in (1). In contrast, the treatment and control groups do not differ—at least not economically—in terms of their capitalization or profitability. They are also similar in terms of their ratio of net interest income to total assets, attesting to the idea that the business models of the two groups of banks are similar.

While by including bank fixed effects, we account for time-invariant unobserved heterogeneity at the bank level, time-varying bank-level variables could partially drive our observed outcomes, which is why we control for a host of *it*-level variables, lagged by one quarter. The set of controls in (1) includes the logarithm of total assets, proxies for indicators from the CAMELS risk rating system, and the average maturity of outstanding bank bonds (as of the

[3]Note that the trends start to diverge a few quarters prior to 2013Q3. This could be because it is difficult to precisely determine the relevant introduction date for the LCR since it was introduced as early as 2010 at Basel III and finalized by the BCBS in January 2013. Moreover, the U.S. also introduced a separate liquidity stress test in November 2012.

end of the prior year), as described in Section 2.2.

To ascertain the role of long-term funding in determining banks' response to the LCR, we use fluctuations in the investment in bank bonds by insurance companies that are themselves not directly affected by the LCR. Instead, insurance companies likely gain importance as investors in bank bonds as the latter are subject to relatively unattractive haircuts for banks under the LCR. As can be seen in Figure 6, insurers' aggregate holdings of bank bonds make for around one-sixth of LCR-affected banks' long-term funding.[4] Thus, to exploit variation in banks' long-term funding stemming from insurers' investment in bank bonds, in additional tests we include, alongside its interaction terms with LCR_i and $Post_t$, $\textit{Ins. bonds/liabilities}_{it}$, ranging from 0 to 100 (%), which is the percentage of total liabilities of bank i consisting of bonds held by insurance companies at the end of the prior year. Note that even a one-percentage-point increase in this variable would substantially increase banks' average maturity of their liabilities.

2.4 Results

Column 1 of Table 3 shows the results from estimating the baseline specification (1) with the fixed effects but no controls. The coefficient on $LCR_i \times Post_t$ is positive and significant at the 1% level, indicating that the introduction of the LCR was associated with an increase in the fraction of liquid assets by around 4.6 percentage points. Column 2 shows that this result is similar when including time-varying bank-level control variables.

To increase the fraction of liquid assets (cf. Figure 1), banks subject to the LCR must implement some combination of increasing the volume of liquid assets and/or decreasing the volume of illiquid assets. To decompose these strategies, Figure 7 shows that the LCR was associated with an increase in liquid assets, while Figure 8 shows that it was associated with

[4] These large intermediaries also make for the vast majority of banks active in the syndicated-loan market, for which we will use transaction-level data in Section 5.

a relatively more striking decrease in illiquid assets. Finally, Figure 9 shows that the LCR was associated with a reduction in total (liquid plus illiquid) assets. These results suggest that banks subject to the LCR increased the fraction of liquid assets primarily by decreasing illiquid assets.

In column 3 of Table 3, we include interactions with the fraction of liabilities consisting of bonds held by insurance companies. The coefficient for the triple interaction is negative, albeit statistically insignificant, indicating that banks with a high degree of long-term funding from insurance companies exhibited a relatively smaller response to the LCR. The coefficient becomes larger and statistically significant in column 4 when restricting the LCR designation to larger banks that were subject to the strict 100% LCR. However, the muting effect of greater funding stability on affected banks increasing their fraction of liquid assets is similar in relative terms, compared to the coefficient on $LCR_i \times Post_t$, across columns 3 and 4. This is consistent with the fact that the LCR requires banks to hold a ratio of high-quality liquid assets to relatively liquid liabilities. As a result, banks with a high degree of long-term funding have a smaller fraction of liquid liabilities and are, thus, less affected by the LCR.

Column 5 shows that the result is similar when using only cross-sectional variation in bank bonds held by insurance companies. In particular, it implements a similar specification as column 4 except using $Ins.\ bonds/liabilities_{it}$ as of the end of 2012, i.e., time invariant. Finally, columns 6 to 10 show the results for the same series of specifications except restricting to bank holding companies with total assets of at least \$10 billion as of 2014Q4. In this case, LCR-affected and unaffected banks are more similar in terms of the primary characteristic that determines their treatment status. In spite of this, the estimates for $LCR_i \times Post_t$ and the interaction with $Ins.\ bonds/liabilities_{it}$ both generally become stronger in magnitude and statistical significance.

The estimated coefficients on the triple interaction match in absolute size those on $LCR_i \times Post_t$. As we measure bank bonds held by the insurance sector as a percentage out of banks' total liabilities, this implies that even a one-percentage-point increase in *Ins. bonds/liabilities*$_{it}$, which ranges from 0 to 100 and would correspond to an average increase in banks' long-term liabilities by roughly 16% (see Table 1), can mute the overall effect of the LCR.

We use heterogeneity in insurance companies' holdings of bank bonds as a source of variation in banks' long-term financing. By using actual holdings, we neglect secondary-market transactions unless they take place among insurance companies. As insurance companies make for some of the most important institutional investors, fluctuations in their actual stock of bank bonds also reflect banks' ability to roll over or raise additional long-term debt from them. That is, even if the amount of bank bonds outstanding may not change, greater demand by insurers may still affect the pricing of banks' long-term debt (Koijen and Yogo, 2019), thereby contributing to funding stability.

Against this background, a potential threat to the identification of this effect may be that rather than reflecting insurers' demand, our estimates capture banks' endogenous supply of long-term bonds, which implicitly targets insurance companies—especially life insurers—that seek to invest in long-term assets. To account for this possibility, we control for the average maturity of all outstanding bonds of a given bank, measured at the same point in time as *Ins. bonds/liabilities*$_{it}$, i.e., at the end of the prior year.

To the extent that illiquid assets—such as loans—tend to be riskier than liquid ones, our results point to potential risk taking by banks with more stable funding in response to tighter liquidity requirements. In the next section, we use a theoretical model to characterize the relationship between liquidity regulation and risk taking in an environment with heterogeneous banks that differ in their funding stability.

3 Model

Motivated by the evidence that the LCR led banks to increase their fraction of liquid assets, this section introduces a model to think about how liquidity risk and liquidity regulations affect bank risk taking. In particular, the model illustrates channels by which tighter 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 there is limited exposure to liquidity stress, i.e., for a higher degree of stable funding. The results of the model are robust to several generalizations and extensions.

3.1 Environment

As an overview of the model, there are three dates $t = 0,1,2$. At date $t = 0$, a risk-neutral, limited-liability 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 some investors withdraw early. The bank can repay these investors by paying out of its liquid assets and, if necessary, by selling a fraction of its illiquid investments to generate additional funds. If the bank cannot fully repay the early investors, 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 investors and keeps the remainder as a profit. If the return is insufficient to fully repay the late investors, then the bank defaults. If the bank defaults in either period, it is liquidated and its assets are redistributed to the investors.

More specifically, at date $t = 0$, the bank acquires funding from a mass 1 of investors that each invest 1 unit in the bank. The investors are protected by deposit insurance. Because investing in the bank is riskless, the bank pays a fixed gross interest rate R on investments withdrawn in period 2. Investments withdrawn in period 1 are returned without interest.[5] A fraction λ of liabilities corresponds to unstable sources of funding that are relatively likely to be withdrawn before the bank's assets mature.

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 of R in period 2.[6,7] The bank can invest the remainder of its funds in long-term assets—e.g., loans to firms and households—that are either safe ($i = s$) or risky ($i = r$). 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 $\frac{1}{2}$. 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 investors withdraw their funds with no interest. Banks can pay investors from their liquid-asset stock.[8] If the bank has insufficient liquid assets to pay the early investors, it can sell a fraction of its illiquid assets. The bank faces a perfectly elastic demand for its long-term assets. Safe assets sell at the price $p_s = p$, while risky assets sell at the lower price $p_r = \delta p$, where $\delta \in (0,1)$. This discount is consistent with the observed empirical pattern between asset risk and illiquidity for banks and non-financial firms alike (Morris and Shin, 2016; Duchin et al.,

[5]See Section 4 for an extension of the model in which the bank can also pay interest on investments that are withdrawn in period 1.

[6]Liquid assets can generally be interpreted to include cash, reserves, and various types of securities, similar to Berger and Bouwman (2009), taking note that the exact definition of liquid assets for a particular regulation may slightly vary. See Section 4 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 in period 2.

[7]Note that the definition of liquidity requirements in the model is intended to be general. While it does not map one-to-one to the LCR, which requires banks to hold liquid assets as a fraction of runnable liabilities rather than total assets, it is consistent with the way banks adjusted their balance sheets to comply with the LCR, as shown in Section 2. Moreover, we show in Section 4 that the main results of the model are robust to alternatively requiring banks to hold a ratio of liquid assets relative to unstable funding λ.

[8]For simplicity, there are no penalties for using liquid assets to respond to liquidity stress. To consider the effect of penalties, see Section 4 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.

2016).

The equity value of the bank is then equal to

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

where $[A]^+ = \max\{A, 0\}$ and $\mathbf{1}_A$ is an indicator function that is equal to 1 when the event A holds and 0 otherwise.

Taking the expectation over the return of the long-term assets, the 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 investors. The payoff is restricted to be non-negative 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 investors, or $\lambda > l$, then the bank must sell a fraction of its long-term assets 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 investors:

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

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 investors:

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

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

Figure 2 summarizes the determination of the bank's equity value. We assume that $q < \delta p$ and $\mu > \max\left\{R, \frac{1-q}{1-\frac{q}{p}} R, \frac{1}{2} \frac{1-q}{1-\frac{q}{\delta p}} R\right\}$ to ensure that it is not profitable for the bank to hold more than the required level of liquid assets. This is consistent with the evidence from Section 2 that the LCR had its intended effect and induced banks to hold a greater fraction of liquid assets, irrespective of whether the LCR was literally binding or banks responded by holding more liquid assets as a buffer relative to their required liquidity.

Proposition 1. *If $q < \delta p$ and $\mu > \max\left\{R, \frac{1-q}{1-\frac{q}{p}} R, \frac{1}{2} \frac{1-q}{1-\frac{q}{\delta p}} R\right\}$, then the bank has no incentive to hold more than the required level of liquid assets.*

Proof. See Appendix A.1. □

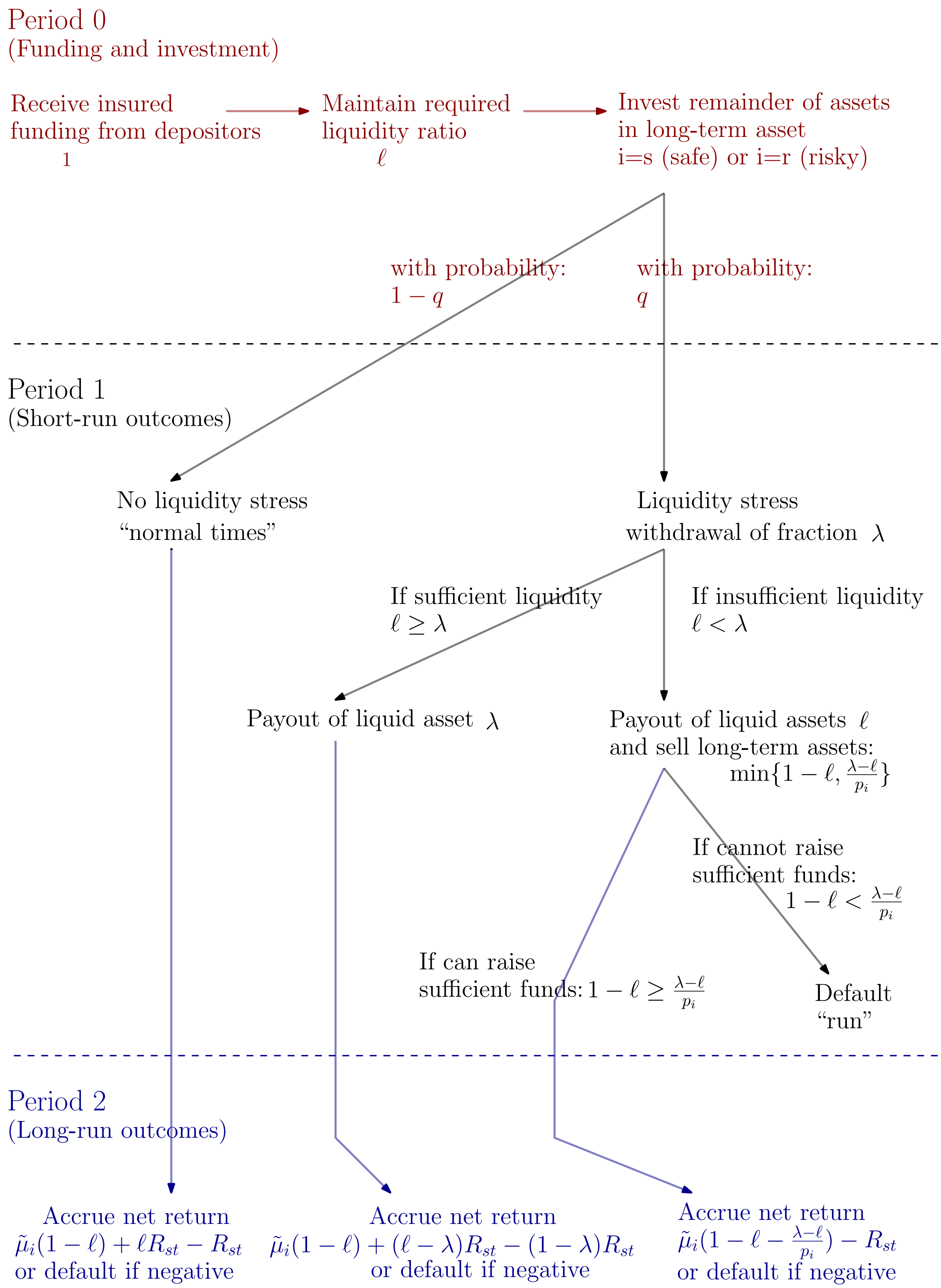
The intuition is that holding liquid assets has the benefit of improving the bank's performance in the liquidity-stress state, but it also has an opportunity cost associated with reducing the bank's investment in higher-yielding long-term assets. Assuming a high expected return on long-term assets μ 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 tendency that the bank does not default due to liquidity stress.*

Proof. See Appendix A.2. □

Figure 2: The Sequence of Events in the Model



The intuition is as follows. On the one hand, holding more 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 investors since it decreases the bank's investment in higher-yielding long-term assets. Restricting to $p < 1$ ensures that this benefit always exceeds the cost.

The parametric restrictions $q < \delta p$, $\mu > \max\left\{ \frac{1-q}{1-\frac{q}{p}} R, \frac{1}{2} \frac{1-q}{1-\frac{q}{\delta p}} R \right\}$, 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 or safe assets in order to maximize its expected profits. Risky assets achieve a higher expected net return in normal times because of the combination of limited liability and deposit insurance, whereas safe assets achieve a higher expected net return when there is a liquidity shock because they can be sold for a higher price, $p_s > p_r$. 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 it invests in risky assets if $\mu < \mu^*$.*

Proof. See Appendix A.3. □

This result reflects 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). This is

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

consistent with the idea that bank equityholders' risk-shifting incentive is larger when bank profitability is low (Jensen and Meckling, 1976).[10]

3.3 The Effect of Tighter Liquidity Requirements 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 portfolio in risky assets. Tightening liquidity requirements is more likely to induce greater risk taking if a bank has a low exposure to liquidity stress, which depends on the fraction of unstable funding λ.

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

Proof. See Appendix A.4. □

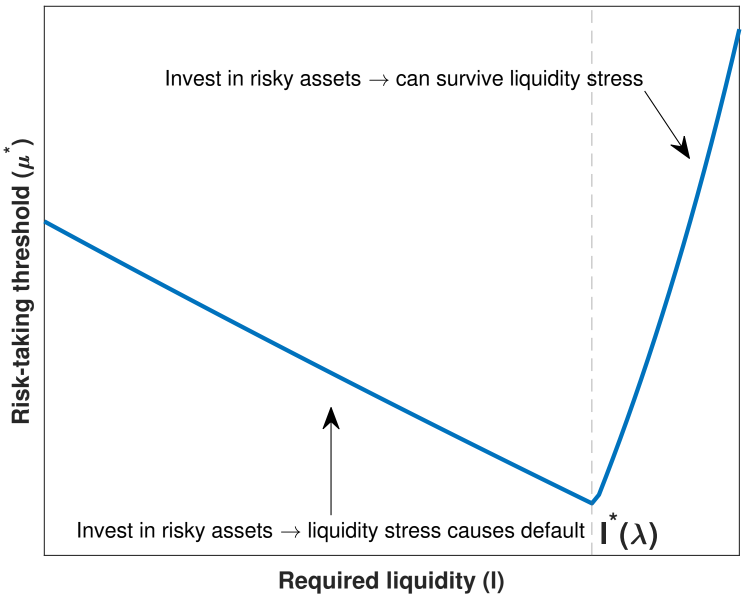
Corollary 1. *The threshold $l^*(\lambda)$ can also be interpreted as the level of liquidity that minimizes the propensity to take risk.*

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 $l < l^*(\lambda)$, 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 price. As a result, if the bank holds risky assets, then marginally tighter liquidity requirements have no effect on the bank's equity value in the liquidity-shock state. However, if the bank holds safe assets, then tighter liquidity requirements increase the bank's performance in the liquidity-shock state.

[10]This is because for a bank with limited liability, the payoff for the equityholders behaves like a call option on the value of the bank with a strike price corresponding to its debt payment, and the sensitivity of the value of the call option to risk is largest around the default threshold.

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.



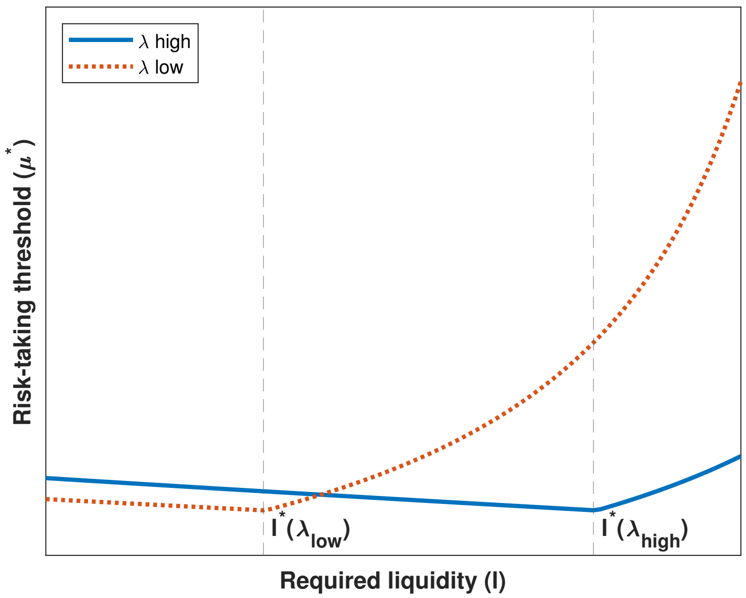
Therefore, tighter liquidity requirements increase the expected return of safe assets relative to risky assets, which decreases the incentive to invest in risky assets ex ante.[11]

By contrast, if the bank has a lower exposure to liquidity stress, or $l > l^*(\lambda)$, then tighter liquidity requirements increase 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, tighter liquidity requirements increase 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 liquidation price. This in turn increases the incentive to invest in risky assets.

[11] Note that this follows from assuming that the 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. 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 long-term assets. In that case, increasing the fraction of liquid assets always increases the incentive to take risk.

Figure 4: Bank Asset Choice and Unstable Funding

This figure compares the risk-taking threshold in the mean return μ^* for different levels of unstable funding.



Reducing the fraction of unstable funding λ decreases a bank's exposure to liquidity stress and, thus, increases the tendency for tighter liquidity requirements to induce greater risk taking.

Proposition 4. *Decreasing the fraction of unstable funding λ increases the range for l on which risk taking increases in the tightness of liquidity requirements:* $\frac{dl^*(\lambda)}{d\lambda} > 0$.

Proof. See Appendix A.5. □

Or put differently, increasing the fraction of unstable funding λ increases the range for l on which banks reduce their risk taking—e.g., they make safer loans—in response to tighter liquidity requirements. Figure 4 illustrates this result graphically. The intuition is that reducing the fraction of unstable funding decreases a bank's exposure to liquidity stress since fewer investors will seek to withdraw before the bank's assets mature. This in turn decreases the probability that the bank will default due to a liquidity shock. The bank therefore becomes less dependent on maintaining a buffer of liquid assets to avoid default. This induces a decrease in the threshold $l^*(\lambda)$ at which the bank can survive liquidity stress even if it invests in risky assets. In Section 5, we take this prediction to the data, and test whether LCR-affected banks are less likely to make safe loans—i.e., whether they are relatively more likely to engage in risk taking—when they have a greater fraction of stable liabilities.

3.4 Optimal Liquidity Regulation

This section finally 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 an investor's own liquidity risk. Specifically, the government insures investors at a gross return of R for late withdrawals and a return of 1 for early withdrawals. The total payout for investors is then given by $T = (1 - \lambda q)R + q\lambda$. The expected payout from banks, denoted by B, includes payments as well as residual assets recovered at a rate $w \in [0,1]$ if the bank defaults. 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 a cumulative distribution function F.

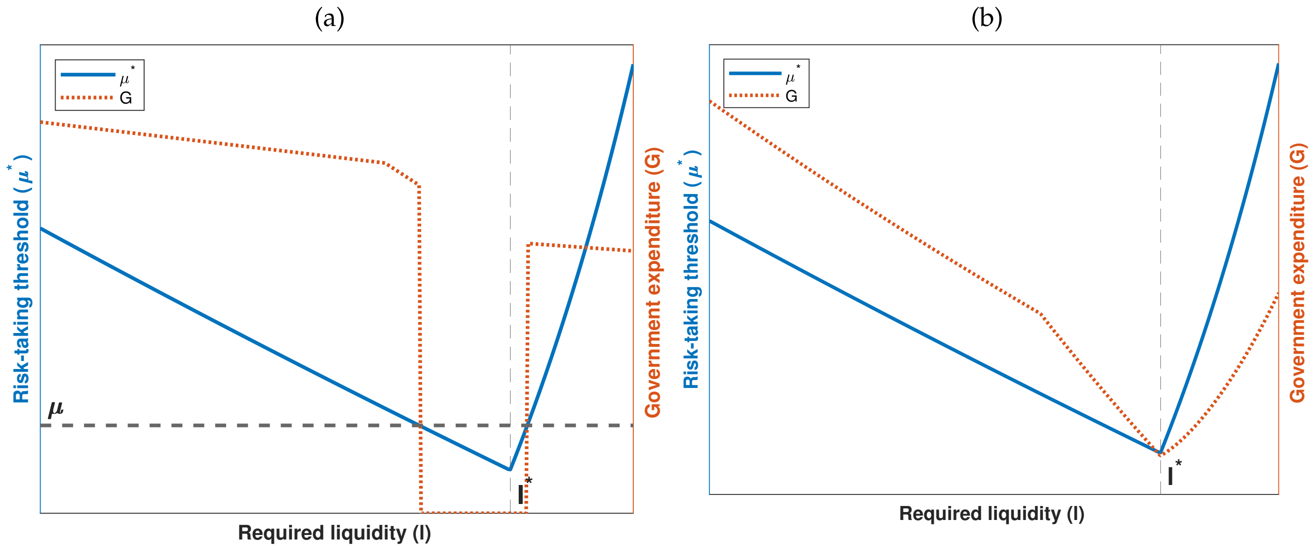
Proposition 5. *The optimal level of liquidity that minimizes the government's expenditure, denoted by l^G, is at least as great as the level $l^*(\lambda)$ that minimizes the fraction of banks that invest in risky assets.*

Proof. See Appendix A.6. □

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

Figure 5: Government Expenditure as a Function of Liquidity Requirements

Panel (a) depicts the government expenditure for a homogeneous mass of banks with expected return μ. Panel (b) depicts the government expenditure for a mass of banks with a uniformly distributed return. The recovery rate is $w = 1$.



the incentive for banks to invest in risky assets. The government then faces a trade-off in which liquidity regulations increase the resilience of banks to liquidity stress, but also increase their incentive to take risk with their remaining illiquid assets.

Figure 5(a) shows the government expenditure for the case of a homogeneous 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 liquidity requirements. 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 the government expenditure for the case of a mass of banks whose expected return is uniformly distributed. The optimal liquidity level that minimizes the government's expenditure is approximately equal to the level $l^*(\lambda)$ 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.

4 Robustness and Extensions

In this section, we probe the results of our model to a host of alternative assumptions. In particular, we generalize the returns of the bank's assets as well as the payment to investors. Furthermore, we define liquidity requirements based on the ratio of liquid assets to runnable liabilities rather than total assets, mirroring the liquidity coverage ratio (LCR). Our results are robust to allowing banks to choose the degree of asset risk, which imposes a cost on investing in risky assets that, for example, could represent risk-based capital requirements, and to allowing the risk of a liquidity shock to vary with a bank's stock of liquid assets. We finally show that many of the implications of increasing long-term funding can also be achieved through an increase in the liquidation price.

4.1 Generalizing the Returns

Appendix B.1 describes conditions under which the results are robust to generalizing the payment to investors and the return on liquid assets in each period. For example, the return on liquid assets must be large enough relative to the payment to investors in order for tightening liquidity requirements to increase the bank's capacity to respond to liquidity stress,[12] but it

[12] Increasing liquid assets could potentially reduce the bank's capacity to survive the fallout in period 2 of a liquidity shock by reducing the bank's investment in long-term assets that generate a higher expected return.

must be small enough in order to maintain the incentive to invest in risky assets. This is because the benefit of risky assets results from reducing the payment to investors net of the return on liquid assets, which is what the bank avoids in cases where it defaults due to a bad return on its long-term assets.

4.2 Definition of Liquidity Requirements

The definition of liquidity requirements in the model is consistent with the way banks adjusted their balance sheets to comply with the LCR, as shown in Section 2. More closely aligned with the definition of the LCR, which requires banks to hold liquid assets as a fraction of runnable liabilities rather than total assets, Appendix B.2 shows that under the assumption that the fraction of unstable funding λ is exogenous, the main results of the model are robust to requiring banks to hold a ratio $\tilde{l}$ of liquid assets relative to unstable funding. This is primarily because the ratio of liquid assets is related to this alternative definition of liquidity requirements by a constant multiple, i.e., $l = \lambda\tilde{l}$.

In general, this alternative definition of liquidity requirements could have different implications for banks' incentives to have stable funding in the first place. This motivates why our empirical analysis focuses on plausibly exogenous variation in stable funding associated with the demand for bank bonds from the insurance sector.

4.3 Continuous Asset Risk

Suppose the return of the long-term asset is

$$\mu + X\epsilon\mu,$$

where $X \in [0,1]$ is the level of risk and $\epsilon \in \{-1,1\}$ is a binary random variable with $P\{\epsilon = -1\} = P\{\epsilon = 1\} = \frac{1}{2}$. In particular, the mean is always equal to μ but the volatility increases with the level of risk X.

The baseline version of the model assumes a binary choice in which X can be either 0 ("safe assets") or 1 ("risky assets"). Let $p(X)$ denote the liquidation price as a function of risk. Appendix B.3 shows that if $q < p(X)$ (consistent with the assumption in Proposition 1) and $\frac{d \log p(X)}{dX} \in \left(-\frac{1}{2}\frac{1-\lambda}{\lambda - l}, 0\right)$, then it is optimal for the bank to invest fully in either risky or safe assets, i.e., choose $X \in \{0,1\}$. As a result, there is no loss of generality in assuming that banks face a discrete asset-risk choice.

The intuition for this result is as follows. If the bank invests sufficiently in risky assets such that a bad return would cause it to default, then it only internalizes the upside of increasing risk in the states where it obtains a high return. The bank can potentially internalize a downside of risk associated with the lower liquidation value in the liquidity-shock state, but the assumption $\frac{d \log p(X)}{dX} > -\frac{1}{2}\frac{1-\lambda}{\lambda - l}$ implies that the upside dominates.

If the bank invests sufficiently little in risky assets such that a bad return will not cause it to fail, then it has no incentive to increase risk since there is no effect on the bank's expected return. Additionally, risky assets have a downside associated with their lower liquidation value in the liquidity-shock state.

4.4 Cost of Risky Assets

Suppose there is a cost C associated with risky assets, which, for example, could represent the effect of risk-based capital requirements.[13] Appendix B.4 shows that as long as the cost is less than $\min\{R(1-\lambda), R(1-l)\}$, the results are qualitatively similar to the baseline model. That is, Propositions 3 and 4 still hold, although the incentive to invest in risky assets diminishes and the threshold $l^*(\lambda)$ increases.

[13] We abstract from general-equilibrium effects whereby capital requirements could actually result in a net decrease in the total cost of capital, e.g., via the scarcity of deposits (Begenau, 2020), or affect default costs, e.g., via the total amount of lending by the banking sector (Malherbe, 2020).

4.5 Additional Comparative Statics of Long-term Funding

Appendix B.5 shows two additional effects of long-term funding:

1. To complement Proposition 4, which shows that decreasing unstable funding λ increases the range for l on which risk taking increases in the tightness of liquidity requirements, Appendix B.5 shows that decreasing unstable funding also results in a relatively more positive effect of tightening liquidity requirements on risk taking for all l, i.e., $\frac{d\mu^*}{dl}$ becomes less negative for $l < l^*(\lambda)$ and more positive for $l > l^*(\lambda)$. Note that this result can also be observed in Figure 4.

2. Regarding the direct effect of stable funding on risk taking, Appendix B.5 shows that μ^* is increasing in λ when $l < l^*(\lambda)$ and decreasing in λ when $l > l^*(\lambda)$. Note that this result can also be observed in Figure 4. The intuition is as follows. When $l < l^*(\lambda)$, the bank only survives the liquidity-shock state if it invests in safe assets. As a result, increasing unstable funding λ worsens the value of the bank in the liquidity-shock state if it invests in safe assets, but has no effect if it invests in risky assets. When $l > l^*(\lambda)$, the bank survives the liquidity-shock state if it invests in either type of assets. As a result, increasing unstable funding worsens the value of the bank in the liquidity-shock state relatively more if the bank invests in risky assets since it increases the amount it must liquidate, which exacerbates the disadvantage of having a lower liquidation value.

4.6 Comparative Statics of the Liquidation Price

Appendix B.6 shows that the effect of increasing the liquidation price p is similar to the effect of increasing the fraction of stable funding in various respects:

1. Increasing the liquidation price increases the range for l on which risk taking increases in the tightness of liquidity requirements (analogous to Proposition 4).

2. Increasing the liquidation price results in a relatively more positive effect of tightening liquidity requirements for all l (analogous to Section 4.5, point 1).

3. The propensity to take risk is decreasing in the liquidation price when $l < l^*(\lambda)$ and increasing in the liquidation price when $l > l^*(\lambda)$ (analogous to Section 4.5, point 2).

Intuitively, these similarities are due to the fact that increasing stable funding and increasing the liquidation price of long-term assets both contribute to the bank's capacity to respond to liquidity stress.

4.7 Effect of Liquidity Regulation on Liquidity-shock Propensity

Suppose liquidity requirements reduce the propensity of a liquidity shock, i.e., $\frac{dq}{dl} < 0$. Appendix B.7 shows that this leads to a relatively more positive effect of tightening liquidity requirements on risk taking for all l, i.e., $\frac{d\mu^*}{dl}$ becomes less negative, or potentially positive, for $l < l^*(\lambda)$ and more positive for $l > l^*(\lambda)$. This is because risky assets perform worse in the liquidity-shock state. However, if $\frac{d\log(q)}{dl}$ is not too low, then Propositions 3 and 4 still hold, i.e., $\frac{d\mu^*}{dl}$ remains negative for $l < l^*(\lambda)$.

5 Liquidity Regulation and Risk Taking: The Role of Banks' Liability Structure

Having theoretically established the importance of banks' funding stability for their risk-taking response to tighter liquidity requirements, we next turn to an empirical test of this core hypothesis of our model. In particular, we test the conjecture in Proposition 4 that a higher fraction of stable funding relatively strengthens banks' incentives to take risk with their illiquid, long-term assets, such as loans.

To this end, we use transaction-level data from the syndicated-loan market, and investigate whether tighter liquidity requirements, which apply only to the subset of LCR-affected banks, affect banks' risk taking within their illiquid-asset portfolio as a function of their liability structure. Consistent with our model, we find that the LCR was associated with riskier loan originations for banks with a greater fraction of stable liabilities, as measured by their long-term funding from insurance companies. As a proof of concept, we present additional evidence of bank risk taking in the context of mortgage loans, using data on loan applications.

5.1 Description of Syndicated-loan Data

To examine risk taking by banks when making new loans, we complement our data (see Section 2.2) with transaction-level data on syndicated loans from the DealScan database. We aggregate the data up to the level of syndicated-loan package-lead bank pairs. That is, our level of observation corresponds to a lead bank's share in a given syndicated-loan package. We identify lead banks/arrangers following Ivashina (2009),[14] and focus on USD-denominated term or revolver loans from U.S. banks to U.S. non-financial companies (i.e., excluding SIC codes $6000 - 6999$).

We merge these data with quarterly balance-sheet data for banks and their borrowers from Compustat to the quarter preceding the active date for each package in DealScan, and we merge the end-of-year insurer-holdings data from NAIC to the year preceding the account filing date in Compustat Bank. We use the merge files associated with Chava and Roberts (2008) and Schwert (2017) to link DealScan with Compustat borrowers and lenders, respectively.

Table 4 presents summary statistics for various bank and borrower characteristics in this transaction-level sample. The bank characteristics are the same as in Table 1 except excluding

[14] If a package has an "administrative agent," then the administrative agents are designated as the lead arrangers. If a package does not have an "administrative agent," then a bank is designated as a lead arranger if it is labeled as an "agent," "arranger," "book-runner," "lead arranger," "lead bank," or "lead manager."

the logarithm of liquid assets and the logarithm of illiquid assets, which are not used in this exercise. The first set of borrower characteristics corresponding to the dependent variables includes the logarithm of the standard deviation of monthly stock returns in the past three years as a measure of ex-ante firm risk—i.e., at the time a loan is made—and the Altman z-score as an inverse measure of credit risk (Altman, 1968). The second set of borrower characteristics corresponding to the controls include the logarithm of total assets as a measure of size, the ratio of market equity to book equity as a measure of investment opportunities, the ratio of debt to assets as a measure of current debt burden, the annualized return on assets as a measure of earnings, and the ratio of tangible (measured as net property, plant, and equipment) to total assets as a measure of collateral.

While in our bank-level sample there are some differences between banks that are affected by the LCR and those that are not, the summary statistics in our transaction-level sample reflect that banks active in the syndicated-loan market tend to be larger. As such, the summary statistics in Table 4 are closer to those for the subgroup of LCR-affected banks in Table 2.

5.2 Regression Specification

We empirically capture bank risk taking by the average risk of firms financed through syndicated loans for which a given bank served as a lead arranger (similarly to, for example, Heider, Saidi and Schepens, 2019). For this purpose, we measure for each lead arranger i of a syndicated loan issued at a date in the quarter following the account filing date t the ex-ante risk of the borrower firm f (in industry $j(f)$). We then estimate the following baseline specification:

$$Y_{ift} = \beta LCR_i \times Post_t + \delta \mathbf{X}_{ift-1} + \psi_i + \rho_{j(f)t} + \epsilon_{ift}, \qquad (2)$$

where Y_{ift} is the logarithm of the borrower's stock-return volatility or the borrower's Altman z-score for a given loan to borrower f in 3-digit SIC industry $j(f)$ by lender i in quarter t, LCR_i is an indicator for whether bank i was subject to the LCR as of 2014Q4 (immediately before the implementation date), $Post_t$ is an indicator for quarters after the proposal date of 2013Q3, $\mathbf{X}_{ift-1}$ is a set of bank-level and firm-level control variables lagged by one quarter, and ψ_i and $\rho_{j(f)t}$ denote, respectively, bank and borrower's industry by year-quarter fixed effects. The set of controls includes the following bank characteristics: the logarithm of total assets and proxies for indicators from the CAMELS risk rating system, and the average maturity of outstanding bank bonds (as of the end of the prior year), as described in Section 2.2. It also includes the following borrower characteristics: the logarithm of total assets, the ratio of market equity to book equity, the ratio of debt to assets, the annualized return on assets, and the ratio of tangible assets to total assets. Standard errors are clustered at the bank level.

Proposition 4 implies that LCR-affected banks engage in relatively more risk taking if they source more long-term funding. As before, we approximate the latter by using variation in insurance companies' investments in bank bonds. We modify (2) accordingly and include interaction terms with $\textit{Ins. bonds/liabilities}_{it}$, which—as before—is the percentage of total liabilities of bank i consisting of bonds held by insurance companies at the end of the prior year. Proposition 4 of the model predicts that the coefficient on the triple interaction term $LCR_i \times Post_t \times \textit{Ins. bonds/liabilities}_{it}$ is positive when using firm f's stock-return volatility as the dependent variable, or negative for its Altman z-score.

We control for the average maturity of banks' outstanding bonds so as to estimate β primarily off insurers' demand for long-term bank bonds, rather than banks' supply thereof. For our estimate to reflect supply and not demand, it would have to be the case that especially banks that engage in risky lending cater to insurance companies. However, insurance companies' capital requirements for corporate bonds are linked to credit ratings (see, among others, Becker and Ivashina, 2015; Becker, Opp and Saidi, 2022). Therefore, the high average credit rating of U.S. banks active in the syndicated-loan market renders it unlikely that yield-searching banks can issue bonds while strategically targeting insurers.

5.3 Results

Column 1 in Table 5 shows the results from estimating the baseline specification (2) with the fixed effects but no controls. The coefficient on $LCR_i \times Post_t$ is negative and significant at the 6% level, indicating that following the introduction of the LCR affected banks grant new loans to firms with a 12.8% lower stock-return volatility. This result is broadly robust to including control variables in column 2 (the coefficient falls just short of being significant at the 10% level), and reflects that LCR-affected banks, on average, grant syndicated loans to safer firms in response to tighter liquidity requirements. This corresponds to our model (Proposition 3) insofar as it reflects that the average level of l in our data falls in the range where μ^* is decreasing in l.

In column 3, we explore to what extent this average estimate masks underlying heterogeneity as a function of banks' funding stability. Our conjecture is that greater funding stability shifts $l^*(\lambda)$ downward and, thus, expands the range where tighter liquidity requirements increase μ^*, rendering it more likely that banks grant riskier loans (Lemma 1). To test this, we add the interaction terms with the fraction of liabilities consisting of bonds held by insurance companies. In line with Proposition 4, the coefficient on $LCR_i \times Post_t \times$ *Ins. bonds/liabilities*$_{it}$ is positive, albeit not statistically significant at conventional levels, potentially indicating that banks with a high degree of funding from insurance companies are relatively more likely to lend to risky firms. This becomes much more pronounced in column 4 when restricting the LCR designation to larger banks that were subject to the strict 100% LCR. Column 5 shows that the result is similar when using *Ins. bonds/liabilities*$_{it}$ as of the end of 2012 to capture only cross-sectional variation in bank bonds held by insurance companies. Finally, Table 6 shows that the results are generally similar when weighting by the deal amount of the package to capture the impact on the overall risk of a bank's syndicated-loan portfolio.

To illustrate this result graphically, Figure 10 compares the average stock-return volatility for companies receiving new syndicated loans from banks with a high or low degree of funding from insurance companies within the set of banks that were subject to the LCR. In particular, the distinction between high vs. low insurance funding is based on a comparison to the median in the prior quarter, which corresponds in spirit to our time-varying variable, *Ins. bonds/liabilities*$_{it}$, in the regressions. While the two groups of banks initially exhibit similar trends, the banks with a high degree of funding from insurance companies showcase a relative increase in the stock-return volatility after the introduction of the LCR. Figure 11 uncovers a similar pattern when alternatively defining the distinction between high vs. low insurance funding based on a time-invariant comparison to the median as of the end of 2012.

Finally, we also implement a similar exercise with the Altman z-score for firms receiving new syndicated loans, which is an inverse measure of default risk. That is, a low value reflects higher default risk. Table 7 shows that our conclusions from Table 5 are broadly similar when using firms' Altman z-scores as the dependent variable.

5.4 Evidence of Bank Risk Taking in the Mortgage Market

As syndicated loans make only for a fraction of banks' total lending, but our theoretical conjecture should apply more broadly to banks' illiquid-asset positions including any kind of bank credit, we complement our empirical analysis of large corporate loans with evidence from the residential mortgage market. For this purpose, we use data from the Home Mortgage Disclosure Act (HMDA) during $2010 - 2017$. We focus on accepted or rejected applications for first lien loans used to purchase owner-occupied, single-family properties. We manually match lenders with at least 1,900 originations during this period to Compustat Bank. Each observation in HMDA is matched to the fourth quarter of the preceding year in Compustat Bank. Table 8 presents summary statistics for our sample.

First, we estimate a regression specification that is directly analogous to (2) on the subsample of applications that converted to originated mortgages and using the borrower's loan-to-income (LTI) ratio as the dependent variable, which has been shown to be a good predictor of mortgage default (Campbell and Cocco, 2015). As HMDA mortgage-origination data are only available annually, we define $Post_t$ as an indicator for applications associated with the years $2014 - 2017$ (after the LCR proposal date of 2013Q3). Additional controls include borrower MSA by year fixed effects, which absorb time-varying unobserved heterogeneity at the borrower's regional level, as well as an indicator distinguishing conventional loans from loans supported by a government program administered by the Federal Housing Administration, Veterans Administration, Farm Service Agency, or Rural Housing Service.

Table 9 shows the results for a similar series of specifications as Table 5. The coefficient on the triple interaction $LCR_i \times Post_t \times Ins.\ bonds/liabilities_{it}$ continues to be positive as well as significant when it designates banks that were subject to the 100% LCR. Banks subject to the LCR increased the portion of risky borrowers, as measured by the latter's LTI ratios, in their mortgage portfolio, in addition to the portion of risky corporate borrowers in their syndicated-loan portfolio, when they sourced more stable funding from insurance companies.

In a second step, we expand our sample by including both accepted and rejected mortgage applications, which are available in the HMDA data. Exploiting this unique feature of the data enables us to better isolate the supply of credit from demand, akin to, for example, Duchin and Sosyura (2014) and Dagher and Sun (2016). To capture banks' lending decisions, we use as the dependent variable an indicator variable for accepted applications. We measure bank risk taking by considering loan-granting decisions for different subsets of loan applicants reflecting their riskiness as measured by their LTI ratios. We interpret a higher likelihood of granting a loan to a riskier borrower as bank risk taking.

In the first three columns of Table 10, we estimate the same regression specifications as in the last three columns of Table 9, but restrict the sample to loan applications from safe borrowers with LTI ratios in the lowest quintile of the respective year, while the last three columns consider loan applications from riskier borrowers with LTI ratios in the highest quintile. The coefficient of interest on the triple interaction $LCR_i \times Post_t \times Ins.\ bonds/liabilities_{it}$ is positive and consistently larger for the pool of riskier loan applicants and only there statistically significant (in columns 5 and 6). This implies that LCR-affected banks with more stable funding are more likely to accept mortgage applications from riskier borrowers, reflecting their risk taking in response to tighter liquidity requirements.

In Table 11, we consider an alternative measure of credit risk and partition the sample based on the ability of a loan to be subsidized. In particular, the sample in columns 1 to 3 is restricted to loans that were either included in one of the above-mentioned government programs or were conventional conforming, i.e., having a loan amount below the conforming loan limit of its corresponding county and therefore eligible for purchase by Fannie Mae or Freddie Mac, the government-sponsored enterprises (GSEs).[15] Lenders have relatively low exposure to the credit risk on these loans since they are likely to be insured by either the government or the GSEs. On the other hand, the sample in columns 4 to 6 is restricted to conventional jumbo mortgages, which are more often kept on the balance sheets of lenders, thereby exposing the latter to credit risk.

In line with our bank-level evidence in Table 3 and Figure 8, LCR-affected banks reduce their exposure to credit risk, as reflected by the negative and statistically significant coefficient on $LCR_i \times Post_t$ in columns 4 to 6, but not in columns 1 to 3 based on the subsample of mortgages eligible for credit-risk transfer. This effect is weakened, however, for LCR-affected banks with more stable funding from insurance companies. The coefficient on the respective triple interaction term is positive and always statistically significant in columns 4 to 6, which is again consistent with the LCR leading to a relatively greater increase in risk taking for banks with more stable funding. In contrast, the triple interaction is either insignificant (columns 1

[15]Note that the sample for this specification starts with applications in 2012, after which changes in the conforming loan limits coincided with the calendar year, which is the reporting period of HMDA.

and 2) or much smaller in magnitude (column 3) for the set of subsidized loans.

6 Conclusion

This paper shows that the liquidity coverage ratio has been associated with an increase in liquidity by banks, and that this has been primarily achieved by reducing the stock of illiquid assets. It then introduces a model to illustrate channels by which liquidity regulations can in turn either increase or decrease the incentive for banks to take risk with their illiquid assets. 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 then increase the incentive to invest in risky assets with a lower liquidation price. The latter effect is more likely to dominate if a bank has a lower exposure to liquidity stress.

Consistent with this prediction, we find that the liquidity coverage ratio is associated with relatively riskier syndicated-loan and mortgage originations for banks with greater funding stability. By illustrating channels by which liquidity risk interacts with credit risk, our analysis sheds light on the potential side effects of liquidity regulation on financial stability.

Our paper also offers insights into some of the consequences of the increasing interdependency of banks and non-banks, in particular insurance companies. We use variation in the maturity composition of banks' liabilities stemming from insurers' investment in bank bonds, giving rise to bank risk taking in response to tighter liquidity requirements. Our findings attest to the idea that overall financial stability is not only affected by the interplay of banks and insurance companies in securities markets (see, for instance, Becker, Opp and Saidi, 2022), thereby affecting banks' asset side, but also by the direct financing of banks through insurance companies.

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Supplementary Figures

Figure 6: Banks' Reliance on Insurance Companies' Investment in Long-term Bonds

This figure shows the mean of the ratio (in percent) of bonds held by insurers to long-term debt, after removing observations where the ratio exceeds 100%, for bank holding companies subject to the LCR vs. those that were exempt from the LCR.

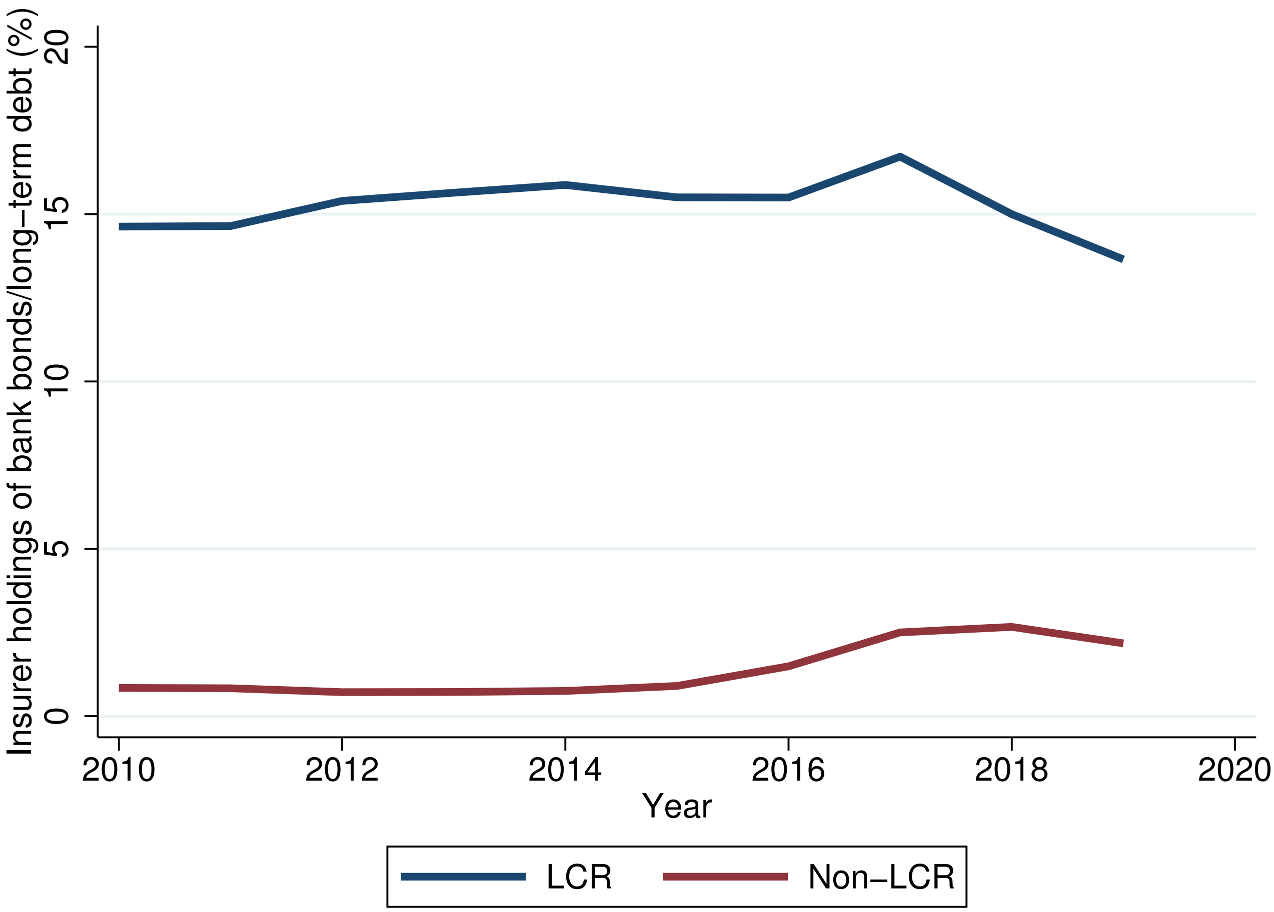


Figure 7: Effect of LCR on Banks' Liquid Assets

This figure shows the mean of the logarithm of liquid assets (cash, balances due from banks, and U.S. Treasury securities) for bank holding companies (BHCs) that were subject to the liquidity coverage ratio (LCR) versus 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.

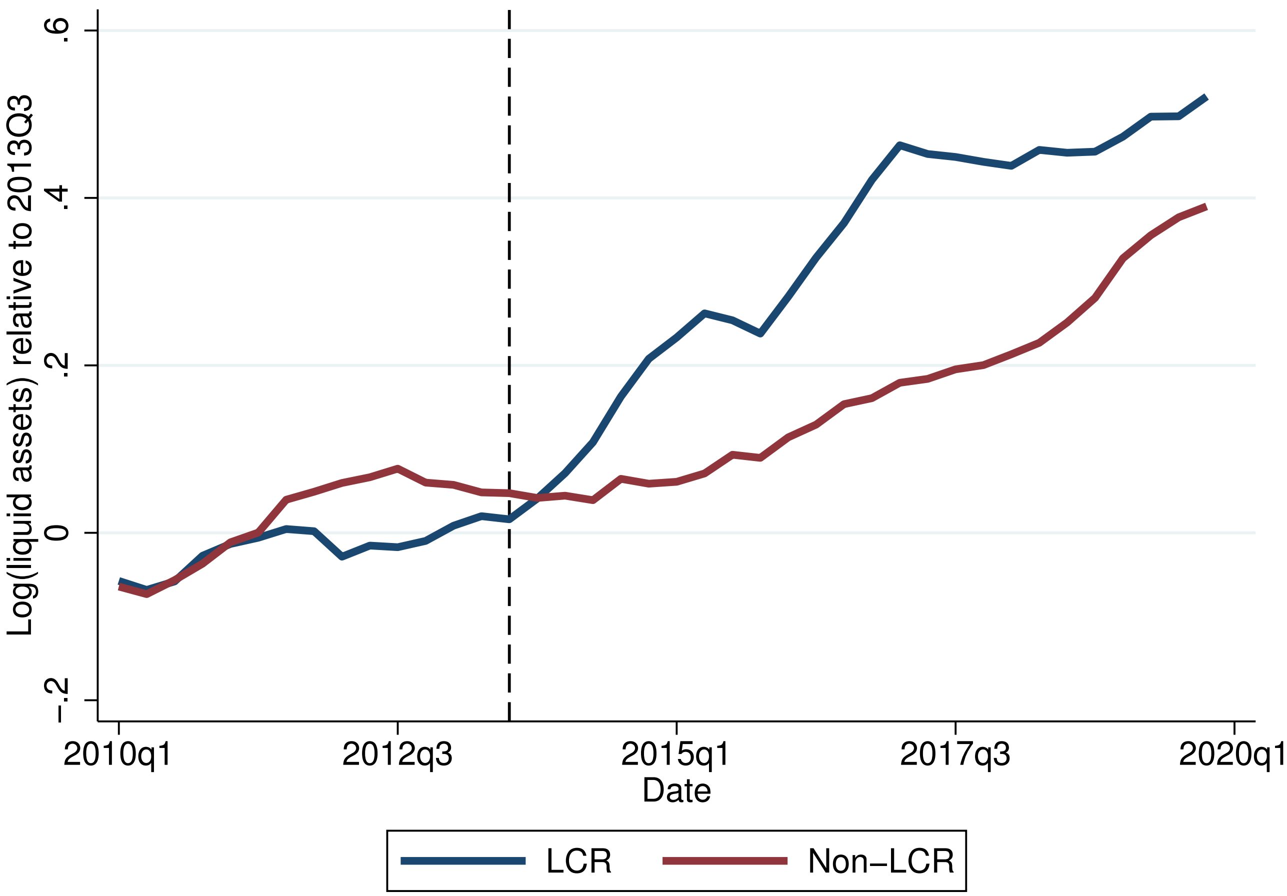


Figure 8: Effect of LCR on Banks' Illiquid Assets

This figure shows the mean of the logarithm of illiquid assets (assets other than cash, balances due from banks, and U.S. Treasury securities) to total assets for bank holding companies (BHCs) that were subject to the liquidity coverage ratio (LCR) versus 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.

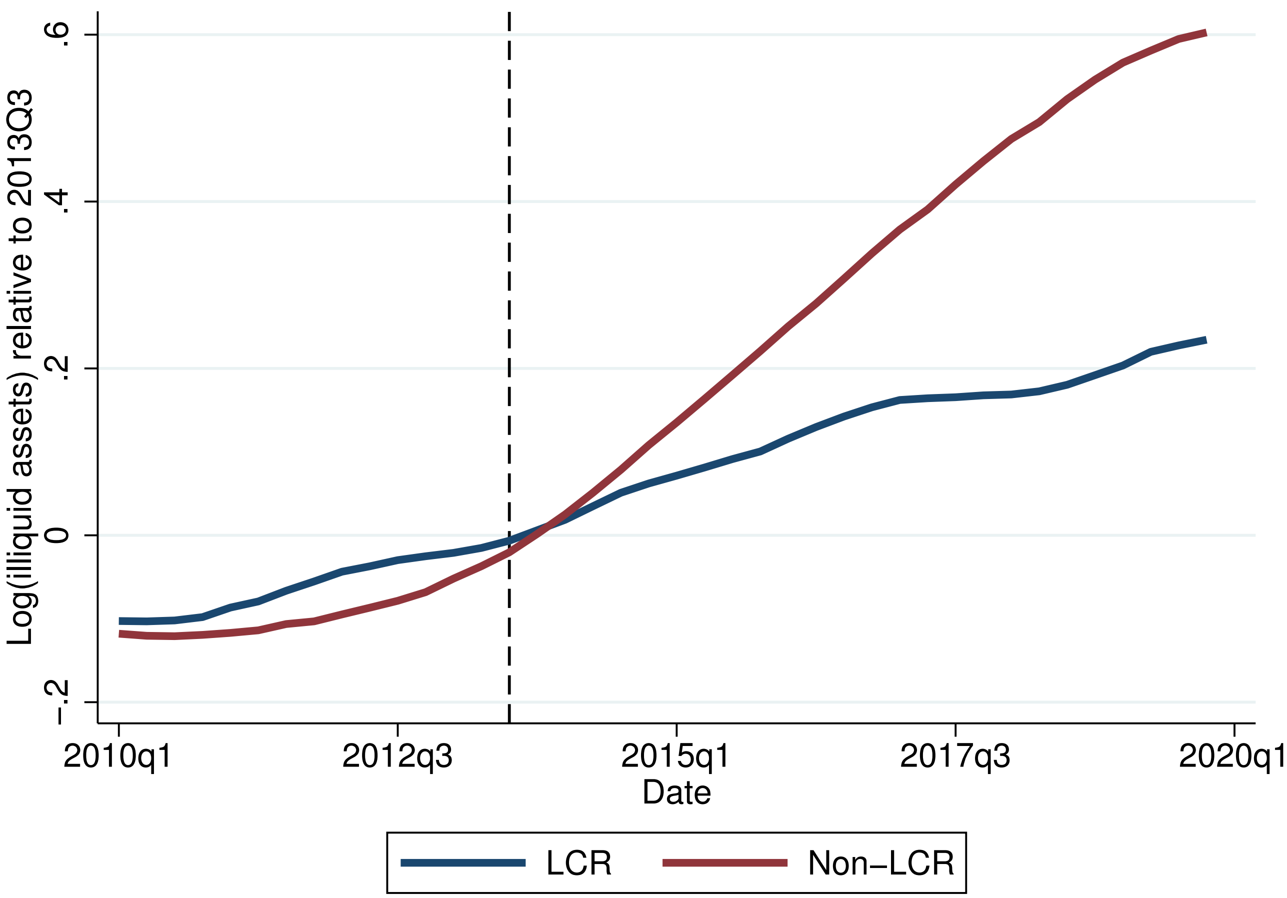


Figure 9: Effect of LCR on Banks' Total Assets

This figure shows the mean of the logarithm of total assets for bank holding companies (BHCs) that were subject to the liquidity coverage ratio (LCR) versus 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.

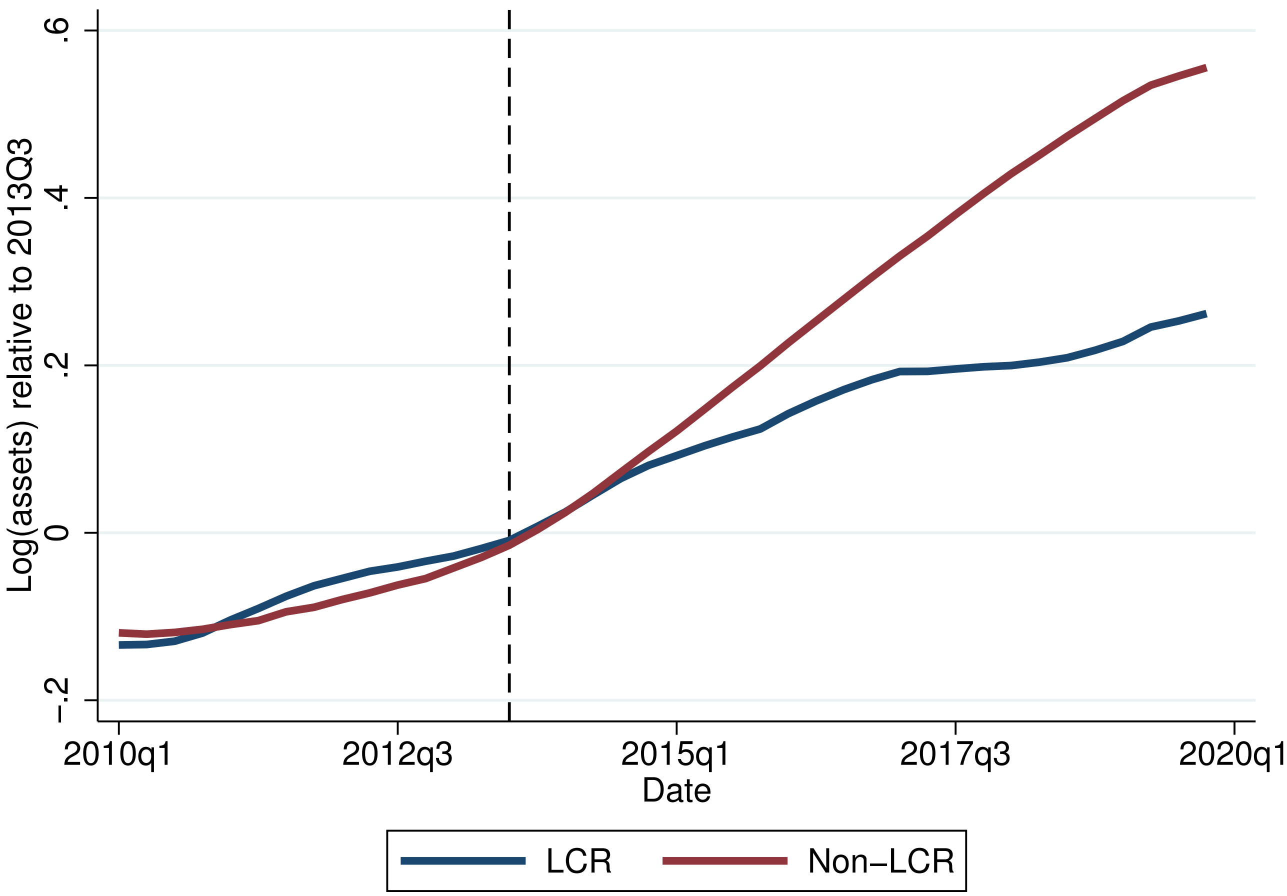


Figure 10: Role of Long-term Funding for Borrowers' Stock-return Volatility among LCR-affected Banks

This figure shows the average stock return volatility (the logarithm of the standard deviation of monthly stock returns in the past 3 years) for companies receiving newly originated syndicated loans for banks with a high or low degree of funding from insurance companies (based on a comparison to the median in the prior quarter) within the set of banks that were subject to 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.

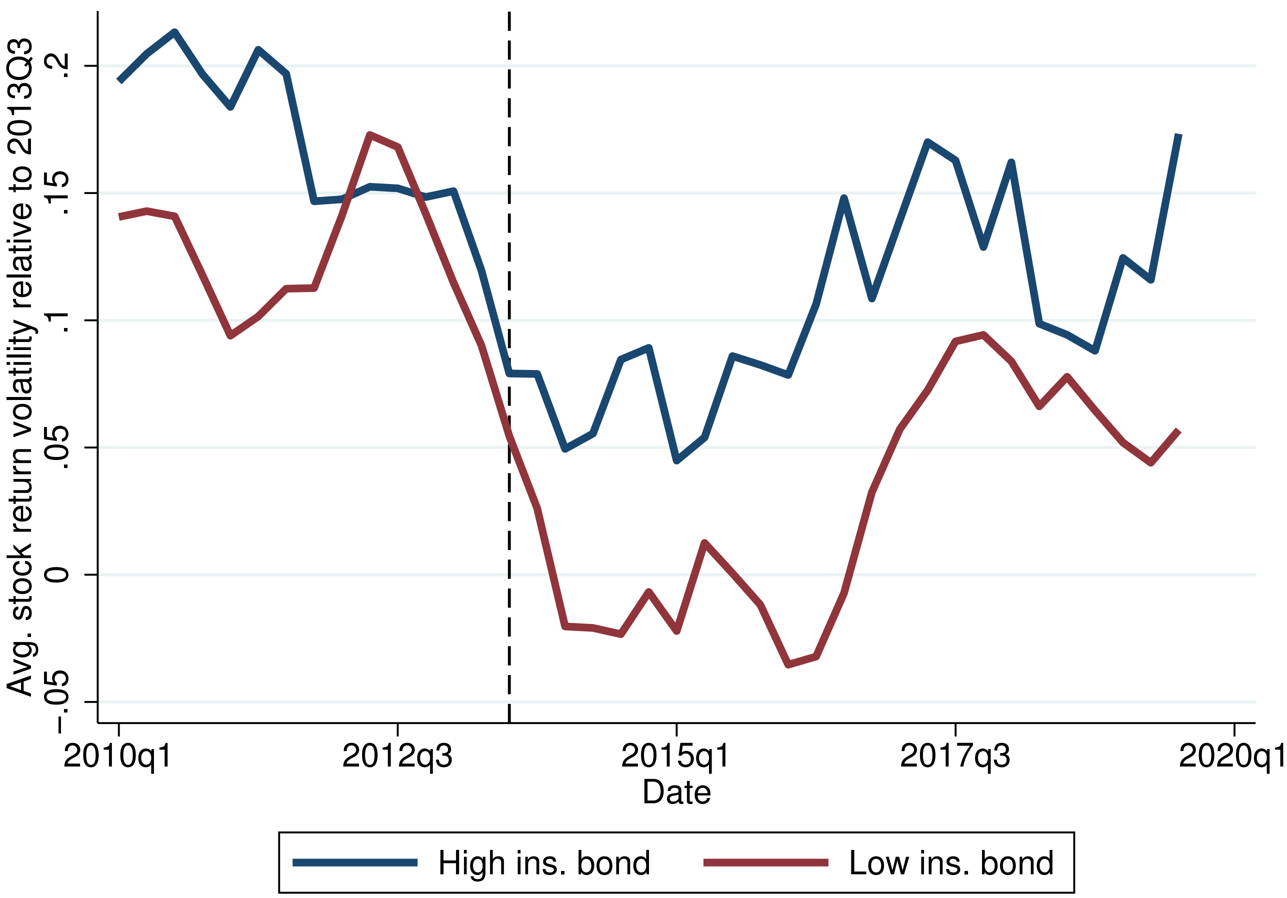


Figure 11: Role of Long-term Funding for Borrowers' Stock-return Volatility among LCR-affected Banks—Robustness to Designation of Insurance Funding

This figure shows the average stock-return volatility (the logarithm of the standard deviation of monthly stock returns in the past 3 years) for companies receiving newly originated syndicated loans for banks with a high or low degree of funding from insurance companies (based on a comparison to the median at 2012Q4) within the set of banks that were subject to 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.

Tables

Table 1: Bank-level Summary Statistics

70% LCR is an indicator for whether a bank met the criteria to be subject to the 70% LCR in 2014Q4. *100% LCR* is an indicator for whether a bank met the criteria to be subject to the 100% LCR in 2014Q4. *Either LCR* is an indicator for whether a bank met the criteria to be subject to either the 70% LCR or the 100% LCR. *Long-term debt/liabilities (%)* is long-term debt divided by total liabilities. *Ins. bonds/liabilities (%)* is the amount of bonds held by insurance companies at the end of the prior year divided by total liabilities, expressed as a percentage. *Ins. bonds/liabilities (cond. > 0)* is Ins. bonds/liabilities restricted to non-zero observations. *Liquid assets/assets (%)* is liquid assets (cash, balances due from banks, and U.S. Treasury securities) divided by total assets, expressed as a percentage. *Log(liquid assets)* is the logarithm of liquid assets. *Log(illiquid assets)* is the logarithm of illiquid assets (assets other than cash, balances due from banks, and U.S. Treasury securities). *Log(assets)* is the logarithm of total assets. *Tier 1 ratio (%)* is Tier 1 capital/risk-weighted assets. *Non-performing assets/loans (%)* is the ratio of non-performing assets to loans net of provisions for losses, expressed as a percentage. *Non-interest expenses/assets (%)* is self-explanatory. *Net income/assets (%)* is the annualized quaterly net income divided by assets, expressed as a percentage. *Sensitivity to market risk (%)* is the absolute difference between short-term assets (cash, balances due from banks, federal funds sold, and securities purchased under agreements to resell) and short-term liabilities (deposits, federal funds purchased, and securities sold under agreements to resell). *Average maturity (years)* is the average maturity of outstanding bonds at the end of the prior year, expressed in the number of years. It is equal to zero if there were no outstanding bonds.

	N	Mean	SD	Min	Max
70% LCR	22,652	0.022	0.147	0.000	1.000
100% LCR	22,652	0.016	0.125	0.000	1.000
Either LCR	22,652	0.038	0.191	0.000	1.000
Long-term debt/liabilities (%)	21,157	6.398	7.703	0.000	96.274
Ins. bonds/liabilities (%)	21,803	0.127	1.108	0.000	42.790
Ins. bonds/liabilities (cond. > 0)	2,259	1.226	3.241	0.000	42.790
Liquid assets/assets (%)	19,622	9.516	9.033	0.130	95.873
Log(liquid assets)	19,624	4.851	1.873	-1.197	13.376
Log(illiquid assets)	19,622	7.536	1.614	-4.343	14.637
Log(assets)	21,695	7.510	1.615	-1.155	14.832
Tier 1 ratio (%)	19,080	13.078	3.785	-13.480	104.100
Non-performing assets/loans (%)	19,772	2.727	7.947	0.000	337.884
Non-interest expenses/assets (%)	21,560	0.882	13.570	0.011	1,990.476
Net income/assets (%)	21,664	0.808	4.936	-25.250	666.667
Sensitivity to market risk (%)	17,211	74.319	9.049	1.179	95.873
Average maturity (years)	22,652	1.628	5.474	0.000	49.000

Table 2: 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 for the period 2010Q1-2013Q3. 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
Long-term debt/liabilities (%)	7.364	9.212	2.064
Ins. bonds/liabilities (%)	0.041	1.231	7.004
Ins. bonds/liabilities (cond. >0)	1.008	1.331	1.115
Liquid assets/assets (%)	10.490	15.487	2.037
Log(liquid assets)	4.541	9.891	14.694
Log(illiquid assets)	7.104	11.948	19.354
Log(assets)	7.137	12.126	19.735
Tier 1 ratio (%)	13.286	12.441	-1.843
Non-performing assets/loans (%)	4.436	2.566	-6.59
Non-interest expense/assets (%)	1.075	0.792	-1.062
Net income/assets (%)	0.631	0.825	1.686
Sensitivity to market risk (%)	73.776	59.820	-4.071
Average maturity (years)	20.654	16.689	-1.73

Table 3: Effect of LCR on Banks' Liquid-asset Ratio

This table presents the results from estimating equation (1) as described in Section 2.3 with the liquid assets ratio as the dependent variable. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating the baseline specification in equation (1) with the fixed effects but no controls. Column (2) shows the results when including the control variables. Column (3) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies. Column (4) estimates the same specification as Column (3) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (5) estimates the same specification a Column (4) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4. Columns (6)-(10) are analogous to columns (1)-(5) except restricting to bank holding companies with total assets of at least $10 billion as of 2014Q4.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Baseline	+ controls	+ funding	100% LCR	Fix date	Baseline	+ controls	+ funding	100% LCR	Fix date
LCR × Post	4.624***	4.094***	3.620*	10.233***	9.018***	4.245**	4.087***	4.818**	10.613***	9.365***
	(2.96)	(3.11)	(1.88)	(9.79)	(7.16)	(2.46)	(2.72)	(2.47)	(9.32)	(7.04)
LCR × Post × Ins. bonds/liab.			-3.186	-8.004***	-8.313***			-6.344**	-8.443***	-8.348***
			(-1.23)	(-3.97)	(-3.57)			(-2.29)	(-3.81)	(-3.57)
LCR × Ins. bonds/liab.			2.882	2.560*				1.522	2.875	
			(1.20)	(1.72)				(0.65)	(1.28)	
Post × Ins. bonds/liab.			3.670*	2.894***	3.993***			6.694***	3.635**	4.330***
			(1.87)	(2.93)	(3.10)			(2.78)	(2.43)	(2.93)
Ins. bonds/liab.			-3.562*	-2.777***				-2.900	-2.751**	
			(-1.81)	(-2.88)				(-1.49)	(-2.12)	
Observations	19,620	14,407	14,294	14,294	13,848	2,675	1,869	1,869	1,869	1,853
R^2	0.776	0.803	0.805	0.805	0.805	0.840	0.861	0.867	0.870	0.868
Controls	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Banks	All	All	All	All	All	Large	Large	Large	Large	Large
Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4: Summary Statistics—Syndicated Loans

70% LCR is an indicator for whether a bank met the criteria to be subject to the 70% LCR in 2014Q4. *100% LCR* is an indicator for whether a bank met the criteria to be subject to the 100% LCR in 2014Q4. *Either LCR* is an indicator for whether a bank met the criteria to be subject to either the 70% LCR or the 100% LCR. *Long-term debt/liabilities (%)* is long-term debt divided by total liabilities. *Ins. bonds/liabilities (%)* is the amount of bonds held by insurance companies at the end of the prior year divided by total liabilities, expressed as a percentage. *Ins. bonds/liabilities (cond. > 0)* is Ins. bonds/liabilities restricted to non-zero observations. *Bank log(assets)* is the logarithm of the bank's total assets. *Tier 1 ratio (%)* is the bank's ratio of Tier 1 capital/risk-weighted assets. *Non-performing assets/loans (%)* is the bank's ratio of non-performing assets to loans net of provisions for losses, expressed as a percentage. *Non-interest expenses/assets (%)* for the bank is self-explanatory. *Net income/assets (%)* is the bank's annualized quarterly net income divided by assets, expressed as a percentage. *Liquid assets/assets (%)* is the bank's ratio of liquid assets (cash, balances due from banks, and U.S. Treasury securities) to total assets, expressed as a percentage. *Sensitivity to market risk (%)* is the bank's absolute difference between short-term assets (cash, balances due from banks, federal funds sold, and securities purchased under agreements to resell) and short-term liabilities (deposits, federal funds purchased, and securities sold under agreements to resell). *Average maturity (years)* is the average maturity of outstanding bonds at the end of the prior year, expressed in the number of years. It is equal to zero if there were no outstanding bonds. *Altman z-score* is the borrower's Altman z-score (Altman, 1968). *Log(stock-return volatility)* is the logarithm of the standard deviation of the borrower's monthly stock returns in the past 3 years. *Borrower log(assets)* is the logarithm of the borrower's total assets. *Market-to-book ratio (%)* is the borrower's ratio of market equity to book equity. *Debt/assets (%)* is the borrower's ratio of debt to assets. *Net income/assets (%)* is the borrower's annualized return on assets. *Tangible assets/assets (%)* is the borrower's ratio of tangible assets to total assets.

	N	Mean	SD	Min	Max
70% LCR	6,772	0.066	0.248	0.000	1.000
100% LCR	6,772	0.927	0.260	0.000	1.000
Either LCR	6,772	0.993	0.086	0.000	1.000
Long-term debt/liabilities (%)	6,772	12.928	3.300	1.285	24.262
Ins. bonds/liabilities (%)	6,772	0.583	0.479	0.085	3.396
Ins. bonds/liabilities (cond. > 0)	6,772	0.583	0.479	0.085	3.396
Bank log(assets)	6,772	14.229	0.895	9.556	14.832
Tier 1 ratio (%)	6,772	12.405	1.023	7.010	16.210
Non-performing assets/loans (%)	6,772	1.756	1.070	0.103	6.173
Non-interest expense/assets (%)	6,772	0.730	0.135	0.443	1.163
Net income/assets (%)	6,772	0.895	0.535	-1.561	10.823
Bank liquid assets/assets (%)	6,765	18.772	6.163	0.450	45.771
Sensitivity to market risk (%)	6,137	46.998	11.290	26.559	85.323
Average maturity (years)	6,772	10.311	4.926	5.174	30.000
Log(stock return volatility)	5,748	-2.406	0.495	-5.234	2.441
Altman z-score	5,515	1.684	131.675	-9,771.599	100.217
Borrower log(assets)	6,622	8.010	1.632	-6.908	13.498
Market-to-book ratio (%)	6,077	313.900	2,973.273	-1.420e+05	75,064.047
Debt/assets (%)	6,618	61.856	34.390	0.000	1,911.429
Net income assets (%)	6,615	-36.468	3,280.432	-2.668e+05	103.025
Tangible assets/assets (%)	6,608	33.838	27.544	0.000	100.000

Table 5: Effect of the LCR on the Riskiness of Borrowers—Stock-return Volatility

This table presents the results from estimating equation (2) as described in Section 5.2 with the logarithm of the borrowing company's stock-return volatility (the standard deviation of monthly stock returns in the past 3 years) as the dependent variable. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating the baseline specification in equation (2) with the fixed effects but no controls. Column (2) shows the results when including the control variables. Column (3) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies. Column (4) estimates the same specification as Column (3) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (5) estimates the same specification as Column (4) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4.

	(1)	(2)	(3)	(4)	(5)
	Baseline	+ controls	+ funding	100% LCR	Fix date
LCR × Post	-0.128*	-0.250	-0.441***	-0.424***	-0.180*
	(-1.98)	(-1.69)	(-3.15)	(-3.90)	(-1.86)
LCR × Post × Ins. bonds/liab.			0.101	0.273***	0.141**
			(0.82)	(3.95)	(2.42)
LCR × Ins. bonds/liab.			-0.165	-0.374	
			(-1.15)	(-1.38)	
Post × Ins. bonds/liab.			-0.147	-0.209***	-0.132**
			(-1.03)	(-4.55)	(-2.56)
Ins. bonds/liab.			0.215	0.162	
			(1.40)	(1.73)	
Observations	3,953	3,472	3,472	3,472	3,388
R^2	0.551	0.633	0.633	0.634	0.634
Controls	No	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes

Table 6: Effect of the LCR on the Riskiness of Borrowers—Stock-return Volatility (Weighted)

This table presents the results from estimating equation (2) as described in Section 5.2 with the logarithm of the borrowing company's stock-return volatility (the standard deviation of monthly stock returns in the past 3 years) as the dependent variable. The regressions are weighted using the deal amount of the loan package. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating the baseline specification in equation (2) with the fixed effects but no controls. Column (2) shows the results when including the control variables. Column (3) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies. Column (4) estimates the same specification as Column (3) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (5) estimates the same specification as Column (4) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4.

	(1) Baseline	(2) + controls	(3) + funding	(4) 100% LCR	(5) Fix date
LCR × Post	-0.210***	-0.360*	-1.182***	-0.318	0.014
	(-3.38)	(-1.83)	(-5.10)	(-1.65)	(0.07)
LCR × Post × Ins. bonds/liab.			0.729***	0.250**	0.090
			(4.62)	(2.46)	(0.84)
LCR × Ins. bonds/liab.			-0.407***	-0.320	
			(-3.26)	(-1.52)	
Post × Ins. bonds/liab.			-0.781***	-0.187*	-0.066
			(-4.80)	(-2.12)	(-0.68)
Ins. bonds/liab.			0.479**	0.129	
			(2.53)	(1.07)	
Observations	3,953	3,472	3,472	3,472	3,388
R^2	0.643	0.701	0.701	0.702	0.699
Controls	No	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes

Table 7: Effect of the LCR on the Riskiness of Borrowers—Altman z-score

This table presents the results from estimating equation (2) as described in Section 5.2 with the borrowing company's Altman z-score (Altman, 1968) as the dependent variable. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating the baseline specification in equation (2) with the fixed effects but no controls. Column (2) shows the results when including the control variables. Column (3) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies. Column (4) estimates the same specification as Column (3) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (5) estimates the same specification as Column (4) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4.

	(1) Baseline	(2) + controls	(3) + funding	(4) 100% LCR	(5) Fix date
LCR $\times$ Post	0.268	1.541	22.446**	1.558*	2.154**
	(0.38)	(0.68)	(2.27)	(2.13)	(2.51)
LCR $\times$ Post $\times$ Ins. bonds/liab.			-26.529**	-1.436**	-2.119**
			(-2.16)	(-2.23)	(-3.21)
LCR $\times$ Ins. bonds/liab.			-0.146	-1.019	
			(-0.15)	(-1.08)	
Post $\times$ Ins. bonds/liab.			26.833**	1.264***	1.582***
			(2.21)	(3.12)	(7.15)
Ins. bonds/liab.			-0.287	-0.025	
			(-0.31)	(-0.05)	
Observations	3,716	3,283	3,283	3,283	3,208
R^2	0.364	0.507	0.511	0.508	0.510
Controls	No	Yes	Yes	Yes	Yes
Industry-quarter FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes

Table 8: Summary Statistics—Mortgage Applications

70% LCR is an indicator for whether a bank met the criteria to be subject to the 70% LCR in 2014Q4. *100% LCR* is an indicator for whether a bank met the criteria to be subject to the 100% LCR in 2014Q4. *Either LCR* is an indicator for whether a bank met the criteria to be subject to either the 70% LCR or the 100% LCR. *Long-term debt/liabilities (%)* is long-term debt divided by total liabilities. *Ins. bonds/liabilities (%)* is the amount of bonds held by insurance companies at the end of the prior year divided by total liabilities, expressed as a percentage. *Ins. bonds/liabilities (cond. > 0)* is Ins. bonds/liabilities restricted to non-zero observations. *Average maturity (years)* is the average maturity of outstanding bonds at the end of the prior year, expressed in the number of years. It is equal to zero if there were no outstanding bonds. *Bank log(assets)* is the logarithm of the bank's total assets. *Tier 1 ratio (%)* is the bank's ratio of Tier 1 capital/risk-weighted assets. *Non-performing assets/loans (%)* is the bank's ratio of non-performing assets to loans net of provisions for losses, expressed as a percentage. *Non-interest expenses/assets (%)* for the bank is self-explanatory. *Net income/assets (%)* is the bank's annualized quarterly net income divided by assets, expressed as a percentage. *Liquid assets/assets (%)* is the bank's ratio of liquid assets (cash, balances due from banks, and U.S. Treasury securities) to total assets, expressed as a percentage. *Sensitivity to market risk (%)* is the bank's absolute difference between short-term assets (cash, balances due from banks, federal funds sold, and securities purchased under agreements to resell) and short-term liabilities (deposits, federal funds purchased, and securities sold under agreements to resell). *Acceptance* indicates if a loan application is accepted. *Conventional* indicates if a loan is conventional, i.e. not associated with a government program .administered by the Federal Housing Administration, Veterans Administration, Farm Service Agency, or Rural Housing Service *Loan-to-income ratio* is the ratio of loan amount to the borrower's income.

	N	Mean	SD	Min	Max
70% LCR	6,058,993	0.146	0.353	0.000	1.000
100% LCR	6,058,993	0.600	0.490	0.000	1.000
Either LCR	6,058,993	0.747	0.435	0.000	1.000
Long-term debt/liabilities (%)	6,058,993	10.244	5.808	0.000	36.232
Ins. bonds/liabilities (%)	5,941,565	0.504	0.546	0.000	3.229
Ins. bonds/liabilities (cond. > 0)	4,714,813	0.635	0.541	0.000	3.229
Average maturity (years)	6,058,993	8.127	8.460	0.000	49.000
Bank log(assets)	6,058,993	12.488	2.233	6.495	14.761
Tier 1 ratio (%)	6,058,993	11.594	1.564	4.500	18.820
Non-performing assets/loans (%)	6,058,993	2.689	2.231	0.094	23.235
Non-interest expense/assets (%)	6,058,993	0.898	0.465	0.271	4.606
Net income/assets (%)	6,058,993	0.816	1.165	-13.744	10.823
Bank liquid assets/assets (%)	5,980,149	12.791	8.104	0.638	35.439
Sensitivity to market risk (%)	5,500,130	60.799	12.421	32.156	86.862
Acceptance	6,058,993	0.841	0.366	0.000	1.000
Conventional	6,058,993	0.657	0.475	0.000	1.000
Loan amount/income	5,917,545	2.844	6.174	0.003	3,835.000

Table 9: Effect of the LCR on the Riskiness of Mortgage Borrowers—Loan-to-Income Ratio

This table presents the results from estimating equation similar to (2) except on a sample of originated mortgages occurring within each year and using the borrowing consumer's loan-to-income ratio as the dependent variable, as described in Section 5.4. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating the baseline specification in equation (2) with the fixed effects but no controls. Column (2) shows the results when including the control variables. Column (3) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies. Column (4) estimates the same specification as Column (3) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (5) estimates the same specification as Column (4) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4.

	(1)	(2)	(3)	(4)	(5)
	Baseline	+ controls	+ funding	100% LCR	Fix date
LCR × Post	-0.074***	-0.039**	-0.040**	-0.023	-0.024
	(-4.49)	(-2.57)	(-2.46)	(-1.66)	(-1.55)
LCR × Post × Ins. bonds/liab.			0.031	0.048***	0.068***
			(0.87)	(3.87)	(4.12)
LCR × Ins. bonds/liab.			-0.062	0.038	
			(-1.15)	(0.84)	
Post × Ins. bonds/liab.			-0.037	-0.034**	-0.035**
			(-1.08)	(-2.59)	(-2.15)
Ins. bonds/liab.			0.066	0.020	
			(1.51)	(0.80)	
Observations	4,315,544	3,880,054	3,846,134	3,846,134	3,796,168
R^2	0.055	0.072	0.068	0.068	0.067
Controls	No	Yes	Yes	Yes	Yes
MSA-year FE	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes

Table 10: Effect of the LCR on the Riskiness of Mortgage Borrowers—Acceptance by Loan-to-Income Ratio

This table presents the results from estimating equation similar to (2) except on a sample of mortgage applications occurring within each year and using an indicator for an accepted application as the dependent variable, as described in Section 5.4. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies and restricts to loan applications where the loan-to-income ratio is in the bottom quintile within the corresponding year. Column (2) estimates the same specification as Column (1) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (3) estimates the same specification as Column (2) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4. Columns (4)-(6) are analogous except restricting to loan applications where the loan-to-income ratio is in the top quintile within the corresponding year.

	(1) + funding	(2) 100% LCR	(3) Fix date	(4) + funding	(5) 100% LCR	(6) Fix date
LCR $\times$ Post	-0.002	0.019	0.014	-0.003	0.007	-0.009
	(-0.07)	(0.95)	(0.48)	(-0.11)	(0.47)	(-0.35)
LCR $\times$ Post $\times$ Ins. bonds/liab.	-0.015	0.021	0.048	0.020	0.042*	0.107**
	(-0.27)	(1.23)	(1.19)	(0.25)	(1.71)	(2.26)
LCR $\times$ Ins. bonds/liab.	0.019	0.154		0.006	0.266***	
	(0.25)	(1.29)		(0.06)	(2.79)	
Post $\times$ Ins. bonds/liab.	0.020	-0.008	0.001	-0.009	-0.019	-0.018
	(0.36)	(-0.51)	(0.04)	(-0.12)	(-1.60)	(-0.92)
Ins. bonds/liab.	0.008	0.016		0.059	0.045***	
	(0.11)	(1.08)		(0.63)	(3.02)	
Observations	913,753	913,753	906,032	997,143	997,143	978,228
R^2	0.051	0.051	0.051	0.061	0.062	0.061
Controls	Yes	Yes	Yes	Yes	Yes	Yes
MSA-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
LTI subsample	Low	Low	Low	High	High	High

Table 11: Effect of the LCR on the Riskiness of Mortgage Borrowers—Acceptance by Subsidization

This table presents the results from estimating equation similar to (2) except on a sample of mortgage applications occurring within each year and using an indicator for an accepted application as the dependent variable, as described in Section 5.4. T-statistics computed using bank-clustered standard errors are reported in parentheses. * indicates statistical significance at the 10% level, ** indicates significance at the 5% level, and *** indicates significance at the 1% level. Column (1) shows the results from estimating a specification that includes interactions with the fraction of liabilities consisting of bonds held by insurance companies and restricts to loan applications that are either associated with a government program or having a loan amount below the conforming loan limit of its corresponding county. Column (2) estimates the same specification as Column (1) except restricting the LCR designation to banks that were subject to the strict 100% LCR. Column (3) estimates the same specification as Column (2) except using the fraction of liabilities consisting of bonds held by insurance companies as of 2012Q4. Columns (4)-(6) are analogous except restricting to loan applications for conventional jumbo loans.

	(1) + funding	(2) 100% LCR	(3) Fix date	(4) + funding	(5) 100% LCR	(6) Fix date
LCR × Post	-0.008	0.024	0.018	-0.085***	-0.032**	-0.040**
	(-0.33)	(1.51)	(0.78)	(-2.99)	(-2.31)	(-2.67)
LCR × Post × Ins. bonds/liab.	0.018	-0.010	0.053**	0.118**	0.037**	0.080***
	(0.32)	(-0.41)	(2.05)	(2.10)	(2.40)	(2.93)
LCR × Ins. bonds/liab.	-0.020	0.425**		-0.168*	0.197*	
	(-0.24)	(2.36)		(-1.87)	(1.82)	
Post × Ins. bonds/liab.	-0.010	-0.014	0.002	-0.094*	-0.014	-0.018
	(-0.18)	(-1.16)	(0.16)	(-1.79)	(-1.02)	(-1.00)
Ins. bonds/liab.	0.037	0.024		0.148**	0.021	
	(0.51)	(1.59)		(2.09)	(0.64)	
Observations	3,105,208	3,105,208	3,048,728	489,458	489,458	488,249
R^2	0.044	0.045	0.044	0.032	0.033	0.032
Controls	Yes	Yes	Yes	Yes	Yes	Yes
MSA-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
Jumbo subsample	No	No	No	Yes	Yes	Yes

Appendices

A Omitted Proofs

A.1 Proof of Proposition 1

Proposition 1. *If $q < \delta p$ and $\mu > \max\left\{R, \frac{1-q}{1-\frac{q}{p}}R, \frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R\right\}$, then the bank has no incentive 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

$$V_r^d = \frac{1}{2}(1-q)[2\mu(1-l) + lR - R] > 0.$$

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

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

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

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

Note that

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

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

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

$$V_s^d = (1-q)[\mu(1-l) + lR - R] > 0.$$

Note that

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

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

$$\begin{aligned} V_s^s = &(1-q)[\mu(1-l) + lR - R] \\ &+ q\left[\mu\left(1 - l - \frac{\lambda - l}{p}\mathbf{1}_{\lambda > l}\right) + (l-\lambda)R\mathbf{1}_{l>\lambda} - (1-\lambda)R\right]. \end{aligned}$$

Note that

$$\begin{aligned} \frac{dV_s^s}{dl} &= (1-q)[-\mu + R] - q\mu + q\mu\frac{1}{p}\mathbf{1}_{\lambda > l} + qR\mathbf{1}_{l>\lambda} \\ &= \left[-\mu\left(1 - \frac{q}{p}\right) + (1-q)R\right]\mathbf{1}_{\lambda > l} \\ &\quad + [-\mu + R]\mathbf{1}_{l>\lambda} < 0 \end{aligned}$$

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

A.2 Proof of Proposition 2

Proposition 2. *If $p < 1$, then holding liquid assets increases the tendency 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 tendency to default in period 1.

Second, we derive conditions under which the bank can repay the early investors 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

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

The threshold for μ at which the bank defaults is

$$\gamma_r=\frac{R(1-\lambda-(l-\lambda)\mathbf{1}_{l>\lambda})}{2\left(1-l-\frac{\lambda-l}{\delta p}\mathbf{1}_{\lambda>l}\right)}. \tag{3}$$

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

$$\gamma_s=\frac{R(1-\lambda-(l-\lambda)\mathbf{1}_{l>\lambda})}{1-l-\frac{\lambda-l}{p}\mathbf{1}_{\lambda>l}}. \tag{4}$$

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:

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

$$\frac{d\gamma_s}{dl}=\frac{-R(1-\lambda)\left(\frac{1}{p}-1\right)}{\left(1-l-\frac{\lambda-l}{p}\right)^2}<0.$$

A.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 it 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 $i = r, s$,[16] which illustrates that a bank cannot default from liquidity stress if it can pay all the early investors 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 $\mu < \gamma_s, \gamma_r$).

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

$$
\begin{aligned}
V_r^d &= \frac{1}{2}(1-q)[2\mu(1-l) + lR - R] \\
V_s^d &= (1-q)[\mu(1-l) + lR - R].
\end{aligned}
$$

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

$$
\Delta V = \frac{1}{2}(1-q)[R - lR] > 0.
$$

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

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

assets can be written as:

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

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 investors.

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:

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

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

$$
\mu^* = \frac{\frac{1}{2}(1-q)[R-lR]+q(1-\lambda)R}{q\left(1-l-\frac{\lambda-l}{p}\right)}. \tag{5}
$$

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

$$\begin{aligned}
V_r^s &= \frac{1}{2}(1-q)[2\mu(1-l)+lR-R] + \frac{1}{2}q\left[2\mu\left(1-l-\frac{\lambda-l}{\delta p}\right)-(1-\lambda)R\right] \\
V_s^s &= (1-q)[\mu(1-l)+lR-R] + q\left[\mu\left(1-l-\frac{\lambda-l}{p}\right)-(1-\lambda)R\right] \\
\Delta V^{s,s} &= \frac{1}{2}R\left[(1-q)(1-l)+q(1-\lambda)\right] - \mu q\frac{(1-\delta)(\lambda-l)}{p\delta} \\
\mu^* &= \frac{\frac{1}{2}R\left[(1-q)(1-l)+q(1-\lambda)\right]}{\frac{q(1-\delta)(\lambda-l)}{p\delta}}.
\end{aligned} \tag{6}$$

Case 5: the bank can respond to liquidity stress without selling its long-term assets
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:[17]

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

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 its long-term assets, the disadvantage of risky assets in the liquidity stress state due to having a lower price is completely avoided.

[17] The superscript "e" in this case stands for excess liquidity.

A.4 Proof of Proposition 3

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

Consider the effect of liquidity regulation 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 regulations on the propensity to take risk is negative:

$$\frac{d\mu^*}{dl} = \frac{-\frac{1}{2}(1-q)R\left(1-l-\frac{\lambda-l}{p}\right) - \left(\frac{1}{p}-1\right)\left[\frac{1}{2}(1-q)[R-lR] + q(1-\lambda)R\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2}$$
$$= \frac{-R(1-\lambda)\left[(1-q)\frac{1}{2p} + q\left(\frac{1}{p}-1\right)\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2} < 0. \quad (7)$$

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

positive:

$$\begin{aligned}\frac{d\mu^*}{dl} &= \frac{\frac{1}{2}R\left[-(1-q)(\lambda-l)+((1-q)(1-l)+q(1-\lambda))\right]}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} \\ &= \frac{\frac{1}{2}R(1-\lambda)}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} > 0. \end{aligned} \tag{8}$$

Case 5: the bank can respond to liquidity stress without selling its long-term assets ($\lambda < l$) 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, tendency for 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 $l^*(\lambda)$ is the threshold between case 3 and case 4, which can also be written as the solution to $\mu^*(l;\lambda) = \gamma_r(l;\lambda)$.

A.5 Proof of Proposition 4

Proposition 4. *Decreasing the fraction of unstable funding λ increases the range for l on which risk taking increases in the tightness of liquidity requirements: $\frac{dl^*(\lambda)}{d\lambda} > 0$.*

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

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

Consider μ^* as computed in case 4 in the proof of Lemma 1 (equation (6)).[18] 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 $\frac{dF}{dl} > 0$. We also

[18]Note that the conclusion is the same if we choose μ^* as computed in case 3 since at $l^*(\lambda)$ the μ^* from case 3 and the μ^* from case 4 are both equal to γ_r.

have

$$\frac{d\mu^*}{d\lambda} = \frac{\frac{1}{2}R\left[-q(\lambda - l) - ((1-q)(1-l) + q(1-\lambda))\right]}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}}$$

$$= \frac{-\frac{1}{2}R(1-l)}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} < 0. \tag{9}$$

and

$$\frac{d\gamma_r}{d\lambda} = \frac{R\left[-\left(1 - l - \frac{\lambda-l}{\delta p}\right) - (1-\lambda)\left(\frac{-1}{\delta p}\right)\right]}{2\left(1 - l - \frac{\lambda-l}{\delta p}\right)^2}$$

$$= \frac{R(1-l)\left(\frac{1}{\delta p} - 1\right)}{2\left(1 - l - \frac{\lambda-l}{\delta p}\right)^2} > 0. \tag{10}$$

Therefore, $\frac{dF}{d\lambda} < 0$. By the implicit function theorem, we have

$$\frac{dl^*(\lambda)}{d\lambda} = -\frac{dF/d\lambda}{dF/dl} > 0.$$

A.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 $l^*(\lambda)$ that minimizes the fraction of banks that invest in risky assets.*

We first compute the government's expected insurance payout G assuming there is a homogeneous mass of banks (or, equivalently, an individual bank) with expected return μ. Note that the total payout for investors is given by $T = (1 - \lambda q)R + q\lambda$. If the expected payout from banks, including payments as well as residual assets recovered at a rate $w \in [0,1]$ if the bank defaults, 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 based on 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 payment to investors is

$$B_{D1} = \frac{1}{2}(1-q)R + w\frac{1}{2}(1-q)Rl + wq[l + \delta p(1-l)].$$

Then, denote the government's expenditure in this case by

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

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 investors is

$$B_{D2} = \frac{1}{2}(1-q)R + w\frac{1}{2}(1-q)Rl + q\lambda + w\frac{1}{2}q2\mu\left(1 - l - \frac{\lambda - l}{\delta p}\right).$$

Then, denote the government's expenditure in this case by

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

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 investors is

$$B_{ND} = \frac{1}{2}(1-q)R + w\frac{1}{2}(1-q)Rl + q\lambda + \frac{1}{2}q(1-\lambda)R.$$

Denote the government's expenditure in this case by

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

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 investors 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 its long-term assets ($\zeta_s, \zeta_r < l < \lambda$ 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 its long-term assets ($\lambda < l$)

In this case, the bank always prefers risky assets. The expected return payment to investors is

$$B_{ND2} = \frac{1}{2}(1-q)R + w\frac{1}{2}(1-q)Rl + q\lambda + \frac{1}{2}q(1-\lambda)R + w\frac{1}{2}q(l-\lambda)R.$$

Therefore

$$G_{ND2} = T - B_{ND2} = (1-\lambda q)R + q\lambda - \left[\frac{1}{2}(1-q)(R+wl) + q\lambda + \frac{1}{2}qR(1-\lambda+w(l-\lambda))\right]. \tag{11}$$

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: ($\lambda < l$): $G = G_{ND2}$.

Government's preferred liquidity level
It is straightforward to see that $G_{D1} \geq G_{D2}$ always holds. It is also clear that $G_{D2} \geq G_{ND} \geq G_{ND2}$ 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 $l \geq l^*(\lambda)$.

B Robustness and Extensions—Details

B.1 Generalizing the Returns

This section describes parametric restrictions under which the main theoretical results of the model are preserved in an extension that generalizes the payment to the investors and the return on liquid assets in each period. In the generalized model, denote the return of investors who withdraw in period t by $R_{d,t}$ and the return on liquid assets in period t by $R_{l,t}$. Note that in the baseline model we have $R_{d,1} = 1$, $R_{l,1} = 1$, $R_{l,2} = R_{d,2} = R$.

We maintain analogous parametric restrictions as in the original model (see Section 3.1): $qR_{l,1} < \delta p$, $p < R_{l,1}$, and $\mu > \max\left\{\frac{1-q}{1-\frac{R_{l}q}{p}}R_{l,2}, \frac{1}{2}\frac{1-q}{1-\frac{R_{l}q}{\delta p}}R_{l,2}\right\}$.[19] 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.[20]

Proposition 6. *The bank has no incentive to hold more than the required level of liquid assets.*

Proof. See Appendix B.1.1. □

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

Proposition 7. *Holding liquid assets increases the bank's capacity to respond to liquidity stress.*

Proof. See Appendix B.1.2. □

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

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

the early investors. 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 investors is not too large compared to its own return on assets.

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 $l^*(\lambda)$ such that μ^* is decreasing in l for $l < l^*(\lambda)$ and μ^* is increasing in l for $l > l^*(\lambda)$.*

Proof. See Appendix B.1.3. □

This result uses the assumptions $R_{d,1} \geq lR_{l,1}$ and $R_{d,2} \geq lR_{l,2}$, which ensure that the return from liquid assets does not exceed the bank's cost of funding. 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 and deposit insurance. The result that μ^* is increasing for $l > l^*(\lambda)$ 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 liquidation price 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 and deposit insurance. 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 regulations is smaller.

Proposition 9. *Decreasing the fraction of unstable funding λ increases the range for l on which risk-taking increases in the tightness of liquidity regulations: $\frac{dl^*(\lambda)}{d\lambda} > 0$.*

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 $l^*(\lambda)$ that minimizes the fraction of banks that invest in risky assets.*

Proof. See Appendix B.1.4. □

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

B.1.1 Proof of Proposition 6

Proposition 6. *The bank has no incentive to hold more than the required level of liquid assets.*

Using similar notation as in the proof of Lemma 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:

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

B.1.2 Proof of Proposition 7

Proposition 7. *Holding liquid assets increases the bank's capacity to respond to liquidity stress.*

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 $R_{l,2} \geq R_{d,2}$ imply:[21]

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

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:

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

[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 $\mu > R_{l,2}$.

B.1.3 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 $l^*(\lambda)$ such that μ^* is decreasing in l for $l < l^*(\lambda)$ and μ^* is increasing in l for $l > l^*(\lambda)$.*

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:

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

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 $\mu^* = \infty$.

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 regulations 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 its long-term assets ($\zeta_s, \zeta_r < l < \frac{R_{d,1}}{R_{l,1}}\lambda$ **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:

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

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 regulations 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 its long-term assets $\left(\frac{R_{d,1}}{R_{l,1}}\lambda < l\right)$
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: $l^*(\lambda)$ is the threshold between case 3 and case 4, which can also be written as the solution to $\mu^*(l;\lambda) = \gamma_r(l;\lambda)$.

B.1.4 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 $l^*(\lambda)$ that minimizes the fraction of banks that invest in risky assets.*

We follow the structure of the proof of Proposition 5. It is straightforward to check that the government's expenditure in each case is the same function of G_{D1}, G_{D2}, G_{ND}, and G_{ND2} as in the proof of Proposition 5, except that we now have:

$$
\begin{aligned}
G_{D1} &= T - B_{D1} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda - \left[\frac{1}{2}(1-q)[R_{d,2} + wlR_{l,2}] + wq[R_{l,1}l + \delta p(1-l)]\right] \\
G_{D2} &= T - B_{D2} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda \\
&\quad - \left[\frac{1}{2}(1-q)[R_{d,2} + wlR_{l,2}] + q\lambda R_{d,1} + \frac{1}{2}wq2\mu\left(1 - l - \frac{R_{d,1}\lambda - R_{l,1}l}{\delta p}\right)\right] \\
G_{ND} &= T - B_{ND} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda - \left[\frac{1}{2}(1-q)[R_{d,2} + wlR_{l,2}] + \frac{1}{2}q(1-\lambda)R_{d,2} + q\lambda R_{d,1}\right] \\
G_{ND2} &= T - B_{ND2} = (1-\lambda q)R_{d,2} + qR_{d,1}\lambda \\
&\quad - \left[\frac{1}{2}(1-q)[R_{d,2} + wlR_{l,2}] + \frac{1}{2}q(1-\lambda)R_{d,2} + w\frac{1}{2}q(l-\lambda)R_{l,2} + q\lambda R_{d,1}\right].
\end{aligned}
$$

It is straightforward to see that $G_{D1} \geq G_{D2}$ always holds. It is also clear that $G_{D2} \geq G_{ND} \geq G_{ND2}$ 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 $l \geq l^*(\lambda)$.

B.2 Definition of Liquidity Requirements

This section shows that the results of the model are robust to allowing liquidity regulation to require the bank to hold a fraction $\tilde{l}$ of liquid assets relative to unstable sources of funding, λ.

It is straightforward to see that analogs of Proposition 1, Proposition 2, and Proposition 3 hold since l and $\tilde{l}$ differ by a constant multiple. In particular, since $l = \lambda\tilde{l}$, each derivative with respect to $\tilde{l}$ is equal to the corresponding derivative with respect to l multiplied by $\lambda > 0$ and therefore has the same sign.

In order to also apply the logic of Proposition 4, it suffices to check that the derivatives with respect to λ also have the same sign. To show this, consider μ^* as computed in case 4 in the proof of Lemma 1 (equation (6)) except replace $l = \lambda\tilde{l}$:[22]

$$
\begin{aligned}
\mu^* &= \frac{\frac{1}{2}R[(1-q)(1-\lambda\tilde{l}) + q(1-\lambda)]}{\frac{q(1-\delta)(\lambda-\lambda\tilde{l})}{p\delta}} \\
&= \frac{\frac{1}{2}R\left[(1-q)\left(\frac{1}{\lambda} - \tilde{l}\right) + q\left(\frac{1}{\lambda} - 1\right)\right]}{\frac{q(1-\delta)(1-l)}{p\delta}}.
\end{aligned} \tag{12}
$$

[22]As mentioned in the proof of Proposition 4, it suffices the consider the μ^* from case 4 since at $l^*(\lambda)$ the μ^* from case 3 and case 4 are both equal to γ_r.

Therefore

$$\frac{d\mu^*}{d\lambda} = \frac{-\frac{1}{2}R}{\frac{q(1-\delta)(1-l)\lambda^2}{p\delta}} < 0. \tag{13}$$

Additionally,

$$\gamma_r = \frac{R(1-\lambda)}{2\left(1-\lambda\tilde{l}-\frac{\lambda-\lambda\tilde{l}}{p}\right)}. \tag{14}$$

Therefore

$$\begin{aligned}\frac{d\gamma_r}{d\lambda} &= \frac{R\left[-\left(1-\lambda\tilde{l}-\frac{\lambda-\lambda\tilde{l}}{\delta p}\right)-(1-\lambda)\left(-\tilde{l}-\frac{1-\tilde{l}}{\delta p}\right)\right]}{2\left(1-\lambda\tilde{l}-\frac{\lambda-\lambda\tilde{l}}{\delta p}\right)^2}\\ &= \frac{R(1-\tilde{l})\left(\frac{1}{\delta p}-1\right)}{2\left(1-\lambda\tilde{l}-\frac{\lambda-\lambda\tilde{l}}{\delta p}\right)^2} > 0.\end{aligned} \tag{15}$$

B.3 Continuous Asset Risk

Suppose the bank is allowed to choose a continuous level of risk $X \in [0,1]$ such that the return of the long-term asset is

$$\mu + X\epsilon\mu,$$

where $\epsilon \in \{-1,1\}$ is a binary random variable with $P\{\epsilon = -1\} = P\{\epsilon = 1\} = \frac{1}{2}$. Let $p(X)$ denote the liquidation price as a function of risk. This section shows that, if $q < p(X)$ (consistent with the assumption in Proposition 1) and $\frac{d \log p(X)}{dx} \in \left(-\frac{1}{2}\frac{1-\lambda}{\lambda-l}, 0\right)$, then it is optimal for the bank to invest fully in either risky or safe assets, ie. choose $X \in \{0,1\}$.

We consider six cases.

Case 1A: the bank fails due to a bad return or a liquidity shock

In this case, the value of the bank is

$$V = \frac{1}{2}(1-q)[(1+X)\mu(1-l) + lR - R], \tag{16}$$

which is clearly maximized at $X = 1$.

Case 1B: the bank fails due to a bad return but survives a liquidity shock by selling its long-term assets

In this case, the value of the bank is

$$V = \frac{1}{2}(1-q)[(1+X)\mu(1-l)+lR-R] + \frac{1}{2}q\left[(1+X)\mu\left(1-l-\frac{\lambda-l}{p(X)}\right)-(1-\lambda)R\right]. \quad (17)$$

Therefore,

$$\begin{aligned}
\frac{dV}{dX} &= \frac{1}{2}(1-q)\mu(1-l)+\frac{1}{2}q\mu\left(1-l-\frac{\lambda-l}{p(X)}\right)+\frac{1}{2}q(1+X)\mu\frac{\lambda-l}{p(X)^2}\frac{dp(X)}{dX} \\
&= \frac{1}{2}\mu\left[(1-l)-q\frac{\lambda-l}{p(X)}\left(1+(1+X)\frac{-1}{p(X)}\frac{dp(X)}{dX}\right)\right] \\
&\underset{q<p(X),\frac{d\log p(X)}{dx}\in\left(-\frac{1}{2}\frac{1-\lambda}{\lambda-l},0\right),X\in[0,1]}{>} \frac{1}{2}\mu\left[(1-l)-(\lambda-l)\left(1+2\left(\frac{1}{2}\frac{1-\lambda}{\lambda-l}\right)\right)\right]=0. \quad (18)
\end{aligned}$$

Therefore the maximum occurs at $X = 1$.

Case 1C: the bank fails due to a bad return but survives a liquidity shock without having to sell any long-term assets

In this case, the value of the bank is

$$V = \frac{1}{2}(1-q)[(1+X)\mu(1-l)+lR-R] + \frac{1}{2}q[(1+X)\mu(1-l)+(l-\lambda)R-(1-\lambda)R], \quad (19)$$

which is clearly maximized at $X = 1$.

Case 2A: the bank does not fail due to a bad return but fails due to a liquidity shock

In this case, the value of the bank is

$$V = (1-q)[\mu(1-l)+lR-R], \quad (20)$$

which is independent of X.

Case 2B: the bank does not fail due to a bad return but survives a liquidity shock by selling its long-term assets

In this case, the value of the bank is

$$V = (1-q)[\mu(1-l) + lR - R] + q\left[\mu\left(1 - l - \frac{\lambda - l}{p(X)}\right) - (1-\lambda)R\right], \tag{21}$$

which is maximized when $X = 0$ since $p(X)$ is decreasing in X.

Case 2C: the bank does not fail due to a bad return but survives a liquidity shock without having to sell any long-term assets
In this case, the value of the bank is

$$V = (1-q)[\mu(1-l) + lR - R] + q[\mu(1-l) + (l-\lambda)R - (1-\lambda)R], \tag{22}$$

which is independent of X.

Summary
Cases 1A, 1B, and 1C imply that if the bank invests enough in the risky assets such that it could default due to a bad return, then it is uniquely optimal to invest fully in risky assets ($X = 1$). Cases 2A, 2B, and 2C imply that if the bank invests enough in safe assets such that it never defaults due to a bad return, then it is optimal to invest fully in safe assets ($X = 0$) and uniquely so in the case where the bank survives a liquidity shock by selling its long-term assets. Even in cases where $X = 0$ is not the unique optimum, the implications for the bank's expected return in each liquidity-shock state are the same.

B.4 Cost of Risky Assets

Suppose there is a cost C associated with risky assets, which could, for example, represent the effect of risk-based capital requirements. This section shows that if $C < \min\{R(1-\lambda), R(1-l)\}$, then Proposition 3 and Proposition 4 still hold, although the incentive to invest in risky assets diminishes and the threshold $l^*(\lambda)$ increases.

Consider the cases from the proof Proposition 3. Note that the value of the bank depending on whether assets are risky or safe and $i = r,s$ and whether or not the bank survives or defaults due a liquidity shock $j = s,d$, V_i^j, is as follows: V_j^s is the same as in Proposition 3, while V_j^r is similar to the expression in Proposition 3 except substracting out C times the probability that the bank does not default. Therefore, in each case, the expression for ΔV is the same as in the proof of Proposition 3 except subtracting out C times the probability that the bank does not default if it invests in risky assets.

Case 1: liquidity stress causes the bank to default if it invests in either type of asset
We have

$$\begin{aligned}\Delta V^{d,d} &= V_r^d - V_s^d \\ &= \frac{1}{2}(1-q)R(1-l) - \frac{1}{2}(1-q)C. \end{aligned} \tag{23}$$

This is positive since $C < \min\{R(1-\lambda), R(1-l)\}$. Therefore the bank always invests in risky assets, or $\mu^* = \infty$, consistent with Proposition 3.

Case 2: liquidity stress causes the bank to default only if it invests in safe assets
It is straightforward to see that $V_r^s - V_s^d > V_r^d - V_s^d$, where $V_r^d - V_s^d > 0$ from case 1. Therefore the bank always invests in risky assets, or $\mu^* = \infty$, consistent with Proposition 3.

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

$$\begin{aligned}\Delta V^{d,s} &= V_r^d - V_s^s \\ &= \frac{1}{2}(1-q)[R-lR] + q(1-\lambda)R - \mu q\left(1 - l - \frac{\lambda - l}{p}\right) - \frac{1}{2}(1-q)C. \end{aligned} \tag{24}$$

Therefore, the threshold μ^* at which $\Delta V = 0$ is given by

$$\mu^* = \frac{\frac{1}{2}(1-q)[R-lR] + q(1-\lambda)R - \frac{1}{2}(1-q)C}{q\left(1 - l - \frac{\lambda - l}{p}\right)}. \tag{25}$$

Note that μ^* is positive since $C < \min\{R(1-\lambda), R(1-l)\}$, and it is clearly decreasing in C. Note also that

$$\frac{d\mu^*}{dl} = \frac{-R(1-\lambda)\left[(1-q)\frac{1}{2p} + q\left(\frac{1}{p} - 1\right)\right] + \frac{1}{2}(1-q)\left(\frac{1}{p} - 1\right)C}{q\left(1 - l - \frac{\lambda - l}{p}\right)^2} < 0, \tag{26}$$

since $C < \min\{R(1-\lambda), R(1-l)\}$, consistent with Proposition 3.

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling its long-term assets
We have

$$\Delta V^{s,s} = V_s^d - V_s^s$$
$$= \frac{1}{2}R\left[(1-q)(1-l) + q(1-\lambda)\right] - \mu q \frac{(1-\delta)(\lambda - l)}{p\delta} - \frac{1}{2}C. \tag{27}$$

Therefore, the threshold μ^* at which $\Delta V = 0$ is given by

$$\mu^* = \frac{\frac{1}{2}R\left[(1-q)(1-l) + q(1-\lambda)\right] - \frac{1}{2}C}{\frac{q(1-\delta)(\lambda-l)}{p\delta}}. \tag{28}$$

Note that μ^* is positive since $C < \min\{R(1-\lambda), R(1-l)\}$, and it is clearly decreasing in C. Note also that

$$\frac{d\mu^*}{dl} = \frac{\frac{1}{2}R(1-\lambda) - \frac{1}{2}C}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} > 0, \tag{29}$$

since $C < \min\{R(1-\lambda), R(1-l)\}$, consistent with Proposition 3.

Case 5: the bank can respond to liquidity stress without selling its long-term assets
We have

$$\Delta V^{e,e} = V_e^d - V_e^s$$
$$= \frac{1}{2}R(1-l) - \frac{1}{2}C > 0 \tag{30}$$

since $C < \min\{R(1-\lambda), R(1-l)\}$. Therefore the bank always invests in risky assets, or $\mu^* = \infty$, consistent with Proposition 3.

Effect on $l^*(\lambda)$
As in the proof of Proposition 4, consider $F(l, \lambda) \equiv \mu^*(l, \lambda) - \gamma_r(l, \lambda)$, using μ^* from case 4

and

$$\gamma_r = \frac{R(1-\lambda)+C}{2\left(1-l-\frac{\lambda-l}{\delta p}\right)}. \tag{31}$$

Case 4 above shows that $\frac{d\mu^*}{dl} > 0$, and it is straightforward to see $\frac{d\gamma_r}{dl} < 0$ since $\delta p < 1$. Therefore $\frac{dF}{dl} > 0$. It is straightforward to see that $\frac{d\mu^*}{dC} < 0$ and $\frac{d\gamma_r}{dC} > 0$, which implies $\frac{dF}{dC} < 0$. Hence, by the implicit function theorem $\frac{dl^*(\lambda)}{dC} > 0$.

Note also that

$$\frac{d\mu^*}{d\lambda} = \frac{-\frac{1}{2}R(1-l)-C}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} < 0 \tag{32}$$

and

$$\frac{d\gamma_r}{d\lambda} = \frac{R(1-l)\left(\frac{1}{\delta p}-1\right)+\frac{2}{\delta p}C}{2\left(1-l-\frac{\lambda-l}{\delta p}\right)^2} > 0. \tag{33}$$

Therefore, $\frac{dF}{d\lambda} < 0$, so by the implicit function theorem $\frac{dl^*}{d\lambda} > 0$, consistent with Proposition 4.

B.5 Additional Comparative Statics of Long-term Funding

Point 1: Interaction with long-term funding for l other than $l^*(\lambda)$

This section shows that decreasing unstable funding also results in a relatively more positive effect of tightening liquidity requirements on risk taking for all l, i.e. $\frac{d\mu^*}{dl}$ becomes less negative for $l < l^*(\lambda)$ and more positive for $l > l^*(\lambda)$.

This result amounts to showing that $\frac{d^2\mu^*}{d\lambda dl} < 0$. Note that μ^* is a finite number in case 3 and case 4 as defined in the proof of Proposition 3, so it suffices to check those two cases.

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

Differentiating $\frac{d\mu^*}{dl}$ in equation (7) by λ obtains

$$\begin{aligned}\frac{d^2\mu^*}{d\lambda dl} &= \frac{R}{q}\frac{\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]\left(1-l-\frac{\lambda-l}{p}\right)^2-\frac{2}{p}\left(1-l-\frac{\lambda-l}{p}\right)\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]}{\left(1-l-\frac{\lambda-l}{p}\right)^4}\\ &= \frac{R\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]\left[1-l-\frac{\lambda-l}{p}\right]\left[1-l-\frac{\lambda-l}{p}-\frac{2}{p}\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^4}<0. \end{aligned} \tag{34}$$

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

It is straightforward to see that $\frac{d\mu^*}{dl}$ in equation (8) is decreasing in λ.

Point 2: Direct effect of long-term funding on risk taking

This section shows that μ^* is increasing in λ when $l<l^*(\lambda)$ and decreasing in λ when $l>l^*(\lambda)$. As explained above, we focus on case 3 and case 4 as defined in the proof of Proposition 3.

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

Differentiating μ^* in equation (5) by λ obtains

$$\begin{aligned}\frac{d\mu^*}{d\lambda} &= \frac{-qR\left(1-l-\frac{\lambda-l}{p}\right)+\frac{1}{p}\left[\frac{1}{2}(1-q)R(1-l)+q(1-\lambda)R\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2}\\ &= \frac{\frac{R(1-l)}{p}\left[q(1-p)+\frac{1}{2}(1-q)\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2}>0. \end{aligned} \tag{35}$$

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

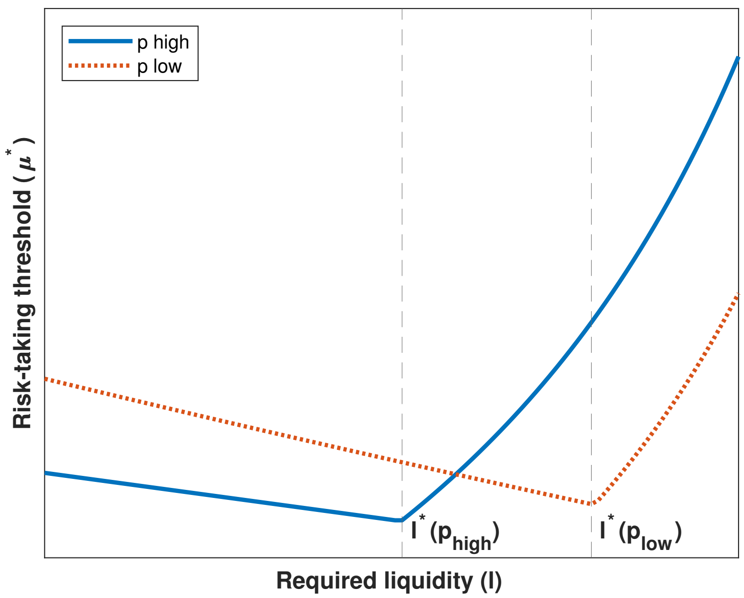
This is shown in (9).

B.6 Comparative Statics of the Liquidation Price

This section shows that increasing the liquidation price p has many similar effects on risk taking incentives as increasing stable funding, i.e. decreasing λ. The similarity can be observed by comparing Figure 4 using the level of stable funding with Figure 12 using the liquidation price. The subsections below establish these similarities analytically.

Figure 12: Bank Asset Choice and Liquidation Price

This figure compares the risk-taking threshold in the mean return μ^* for different levels of the liquidation price p.



Note that μ^* is a finite number in case 3 and case 4 as defined in the proof of Proposition 3, so in each of the arguments below we focus on just these two cases.

Point 1: Effect of the liquidation price on $l^*(\lambda)$

Similar to the proof of Proposition 4, consider $F(l,p) \equiv \mu^*(l,p) - \gamma_r(l,p)$, using μ^* from case 4. The proof of Proposition 4 shows that $\frac{d\mu^*}{dl} > 0$ and $\frac{d\gamma_r}{dl} < 0$, which implies $\frac{dF}{dl} > 0$. It is also straightforward to see that $\frac{d\mu^*}{dp} > 0$ and $\frac{d\gamma_r}{dp} < 0$, which implies $\frac{dF}{dp} > 0$. Hence, by the implicit function theorem, we have that $\frac{dl^*(\lambda)}{dp} < 0$.

Point 2: Interaction with liquidation price for l other than $l^*(\lambda)$

Case 3: liquidity stress causes the bank to default only if it invests in risky assets
It is straightforward to see by inspection that $\frac{d\mu^*}{dl}$ in equation (7) satisfies $\frac{d^2\mu^*}{dpdl} > 0$.

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling its long-term assets
It is straightforward to see by inspection that $\frac{d\mu^*}{dl}$ in equation (8) satisfies $\frac{d^2\mu^*}{dpdl} > 0$.

Point 3: Direct effect of the liquidation price on risk taking

Case 3: liquidity stress causes the bank to default only if it invests in risky assets
It is straightforward to see by inspection that μ^* in equation (5) is decreasing in p.

Case 4: the bank can remain solvent in the face of liquidity stress with either type of asset by selling its long-term assets
It is straightforward to see by inspection that μ^* in equation (6) is increasing in p.

B.7 Effect of Liquidity Regulation on Liquidity-shock Propensity

This section shows that if $\frac{d\log(q)}{dl} \in \left(\frac{-(1-\lambda)\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]}{\frac{1}{2}(1-l)\left(1-l-\frac{\lambda-l}{p}\right)}, 0\right)$, then tightening liquidity requirements has a relatively more positive effect on risk taking, while Proposition 3 and Proposition 4 still hold.

Note that μ^* is a finite number in case 3 and case 4 as defined in the proof of Proposition 3, so it suffices to check those two cases.

Case 3: liquidity stress causes the bank to default only if it invests in risky assets
In this case, the total derivative of μ^* (equation (5)) with respect to l is now given by

$$\begin{aligned}\frac{d\mu^*}{dl} &= \frac{\partial\mu^*}{\partial l} + \frac{\partial\mu^*}{\partial q}\frac{dq}{dl} \\ &= \frac{-R(1-\lambda)\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]}{q\left(1-l-\frac{\lambda-l}{p}\right)^2} - \frac{\frac{1}{2}R(1-l)}{q\left(1-l-\frac{\lambda-l}{p}\right)}\frac{1}{q}\frac{dq}{dl}. \end{aligned} \tag{36}$$

Note that the second term is positive since $\frac{dq}{dl} < 0$, which implies that tightening liquidity requirements has a relatively more positive effect on risk taking. However, if $\frac{d\log(q)}{dl} > \frac{-(1-\lambda)\left[(1-q)\frac{1}{2p}+q\left(\frac{1}{p}-1\right)\right]}{\frac{1}{2}(1-l)\left(1-l-\frac{\lambda-l}{p}\right)}$, then $\frac{d\mu^*}{dl}$ is still negative, consistent with Proposition 3.

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

In this case, the total derivative of μ^* (equation (6)) with respect to l is now given by

$$\begin{aligned}\frac{d\mu^*}{dl} &= \frac{\partial\mu^*}{\partial l} + \frac{\partial\mu^*}{\partial q}\frac{dq}{dl} \\ &= \frac{\frac{1}{2}R(1-\lambda)}{\frac{q(1-\delta)(\lambda-l)^2}{p\delta}} - \frac{\frac{1}{2}R(1-l)}{\frac{q(1-\delta)(\lambda-l)}{p\delta}}\frac{1}{q}\frac{dq}{dl}. \end{aligned} \tag{37}$$

Note that the second term is positive since $\frac{dq}{dl} < 0$, which implies that tightening liquidity requirements has a relatively more positive effect on risk taking.

Effect on $l^*(\lambda)$

It is straightforward to see that the proof of Proposition 4 still follows since allowing q to decrease with l has no effect on the signs of the derivatives of the case 4 μ^* (equation (6)) and γ_r (equation (3)) with respect to l or λ.