Liquidity Regulation and Bank Risk Taking on the Horizon*

Joshua Bosshardt
Federal Housing Finance Agency

Ali Kakhbod
UC Berkeley

Farzad Saidi
University of Bonn & CEPR

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Abstract

We examine how banks' liquidity requirements may affect their incentives to take risk with their remaining illiquid assets. Our simple model predicts that banks with a greater share of stable liabilities are more likely to engage in risk taking in response to tighter liquidity requirements. This prediction is borne out in syndicated-loan data 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.

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Bosshardt: Federal Housing Finance Agency, 400 7th Street SW, Washington, DC 20219, USA. E-mail: jjbosshardt@gmail.com.
Kakhbod: University of California, Berkeley, Haas School of Business, 2220 Piedmont Ave, Berkeley, CA 94720, USA. E-mail: akakhbod@berkeley.edu.
Saidi: University of Bonn, Reinhard Selten Institute, Niebuhrstr. 5, 53113 Bonn, Germany. E-mail: saidi@uni-bonn.de.

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 bank bonds, we test this prediction empirically. We find that banks that see more investments in their long-term bonds 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 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), which can in turn affect banks' ability to access or maintain long-term funding. 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.

We start out by documenting two facts about how banks directly adjusted their balance sheet 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.

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 a relatively high degree of long-term funding supplied by insurance companies increase their liquid-asset ratio by 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 riskiness 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 liquid 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 assets relative to risky assets in states where the bank faces liquidity stress, which in turn increases the incentive to invest in safe assets ex ante.

By contrast, the bank has a 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.

Our 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 illiquid assets is consistent with this 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 their asset-side composition. 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 greater stable funding, as measured by the fraction of liabilities consisting of bonds held by insurance companies. We characterize bank risk taking by the ex-ante riskiness of firms financed by (lead) banks in syndicated loans (similarly to, for example, Heider, Saidi and Schepens, 2019). Our results hold up to using book-value and market-value based measures of firm risk. We conclude from them that while the LCR can be effective in bolstering resilience to short-term liquidity risk, tighter liquidity requirements may also 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. In particular, a number of theoretical papers shed light on the potential use of liquidity regulation by characterizing its interaction with other regulatory requirements, especially capital requirements, and interventions such as the lender-of-last-resort (LOLR) function of central banks. For instance, Santos and Suárez (2019) argue that imposing stricter liquidity requirements may strengthen the efficiency of LOLR policies. 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 riskiness 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. A notable exception is the event study conducted by Bruno, Onali and Schaeck (2018) who find that liquidity-regulation announcements between 2010 and 2015 were associated with negative abnormal returns of European bank stocks. Banerjee and Mio (2018) show that the Individual Liquidity Guidance, a precursor to the LCR in the UK, led banks to decrease lending to financial firms, but they do not find evidence that it reduced the amount of lending to non-financial firms. Bonner and Eijffinger (2016) show that a precursor of the LCR in the Netherlands was associated with higher long-term interbank lending rates. In the U.S., Sundaresan and Xiao (2022) provide evidence that the LCR led banks to acquire liquidity by borrowing more from the Federal Home Loan Banks, while Roberts, Sarkar and Shachar (2022) show that the LCR has been associated with reduced liquidity creation.

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 idea underlying this literature 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 among bank investors (Bryant, 1980; Diamond and Dybvig, 1983; Ahnert and Kakhbod, 2017). We depart from this literature by analyzing how regulations that mitigate liquidity risk during crises affect banks' exposure to other kinds of risk. In particular, we empirically identify how the 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) and taxation (e.g., Célérier, Kick and Ongena, 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, forthcoming). 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 sheet 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.[1]

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.

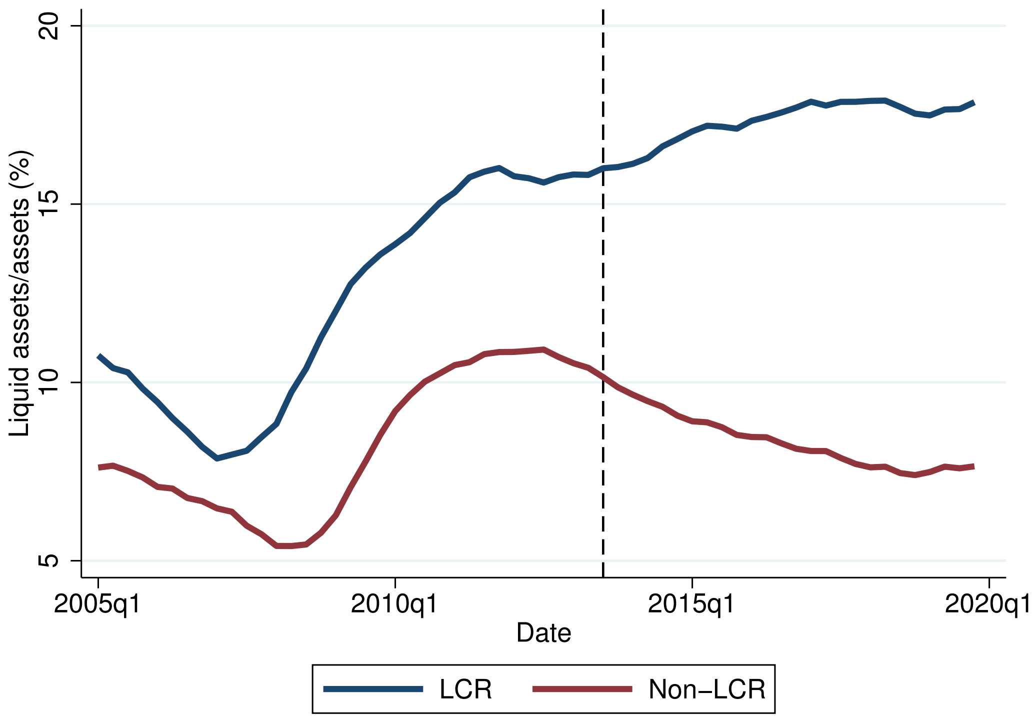
Table 1 presents summary statistics for various bank characteristics. The first set of variables corresponding to the primary explanatory variables includes an indicator for whether a bank met the criteria to be subject to either type of the LCR as of 2014Q4 (immediately before the implementation of the LCR) as well as the percentage of total liabilities (or long-term debt) consisting of bank bonds held by insurance companies.

The second set of variables corresponding to the dependent variables includes liquid

[1]See Hong, Huang and Wu (2014) for more details about the computation of high-quality liquid assets and net cash outflows.

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.



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]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.

2.3 Empirical Strategy

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

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

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, 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

[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.

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 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.

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 a relatively more striking decrease in illiquid assets. Finally, Figure 9 shows that the LCR was associated with a reduction in total assets. These results suggest that banks subject

[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 4.

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 6-10 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.

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 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.

3.1 Environment

As an overview of the model, there are three dates $t = 0,1,2$. At date $t = 0$, a 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 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] 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.[7] 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., 2016).

The equity value of the bank is then equal to

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

[5] See Section 3.5 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 3.5 for an extension of the model in which the return on liquid assets can be different from 1 in period 1 and different from R in period 2.

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

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 nonnegative due to limited liability.

The second term averages over states in which a liquidity shock occurs. If the bank's liquid assets are insufficient to repay the early 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.

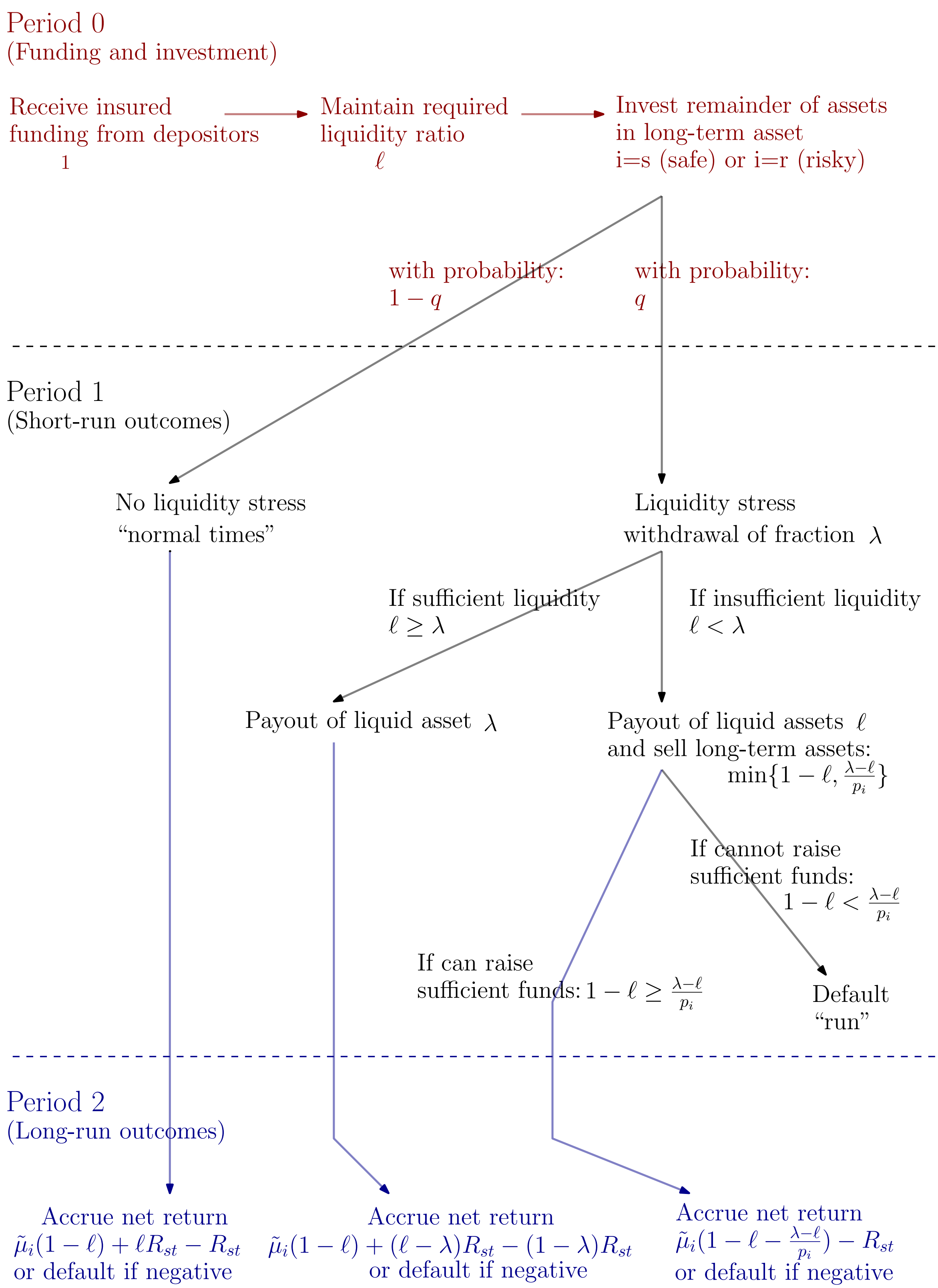
Figure 2 summarizes the determination of the bank's equity value. We assume that $q < \delta p$ and $\mu > \max\left\{R, \frac{1-q}{1-\frac{q}{p}}R, \frac{1}{2}\frac{1-q}{1-\frac{q}{\delta p}}R\right\}$ to ensure that it is not profitable for the bank to hold more than the required level of liquid assets. 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 never wants to hold more than the required level of liquid assets.*

Proof. See Appendix B. □

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

Figure 2: The Sequence of Events in the Model



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 B. □

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.[8]

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 limited liability, whereas safe assets achieve a higher expected net return when there is a liquidity shock because they can be sold for a higher price, $p_s > p_r$. 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.

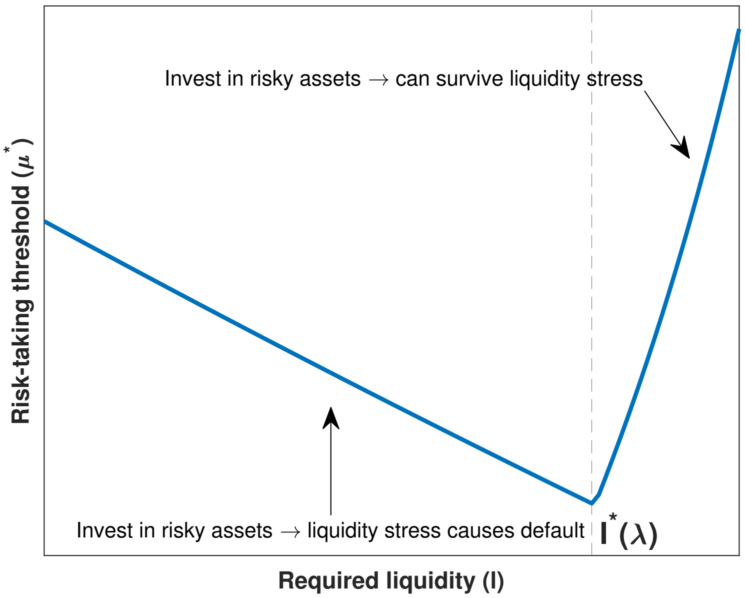
Lemma 1. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$, and it invests in risky assets if $\mu < \mu^*$.*

Proof. See Appendix B. □

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

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.



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 consistent with the idea that bank equityholders' risk-shifting incentive is larger when bank profitability is low (Jensen and Meckling, 1976).[9]

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 B. □

[9] 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.

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. 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.[10]

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.

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: $\frac{dl^*(\lambda)}{d\lambda} > 0$.*

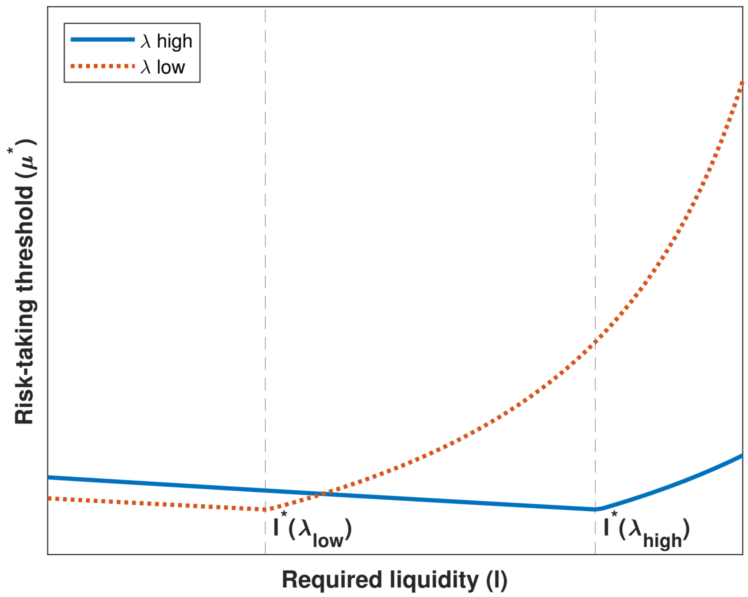
Proof. See Appendix B. □

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

[10]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.



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.

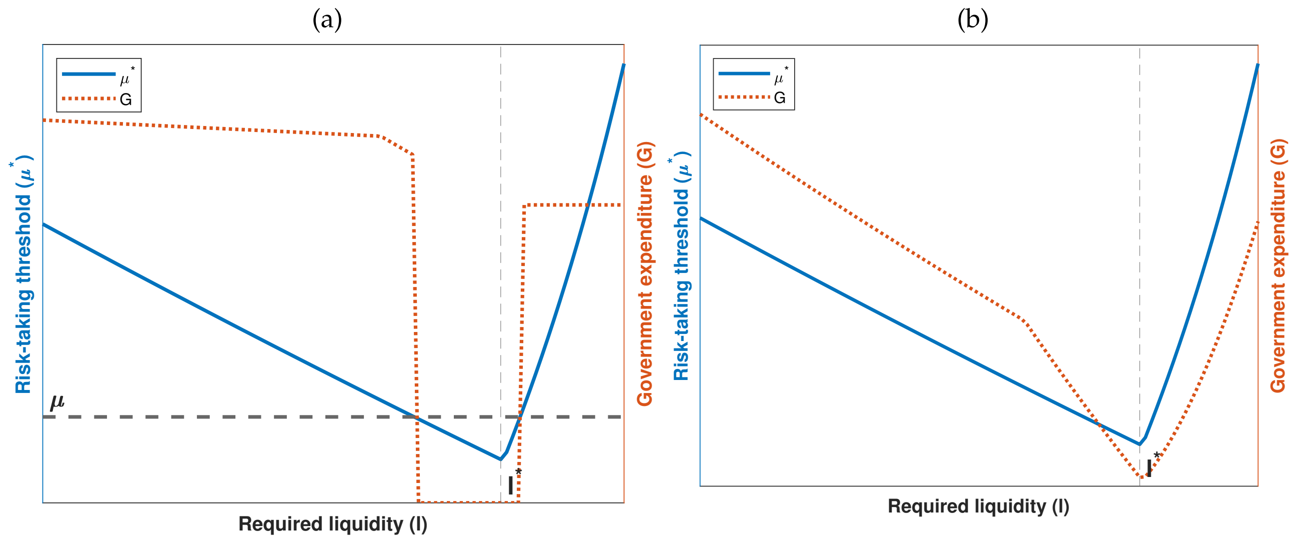
In Section 4, we take this prediction to the data, and test whether LCR-affected banks are less likely to make safe loans—i.e., whether they are relatively more likely to engage in risk taking—when they have a greater fraction of stable liabilities.

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 $T = (1 - \lambda q)R + q\lambda$. If the expected payout from banks is equal to B, then the government must pay the difference $G = T - B$. Suppose there is a mass 1 of banks whose expected return μ is distributed with a cumulative distribution function F.

Figure 5: Government Expenditure as a Function of Liquidity Requirements

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



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 B. □

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 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.

3.5 Extensions

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

4 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 hold constant the fraction of illiquid assets, and test the conjecture in Proposition 4 that a higher fraction of stable funding relatively strengthens banks' risk-taking response to liquidity regulation.

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.

4.1 Description of Additional 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 following Ivashina (2009),[11] 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 active date. 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 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 characters 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 stark 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.

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

4.2 Regression Specification

We empirically capture bank risk taking by the average riskiness 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 bank i of a syndicated loan issued at a date in quarter t the ex-ante riskiness of the borrower firm f (in industry $j(f)$). We then estimate the following baseline specification:

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

where Y_{ift} is the borrower's stock-return volatility or 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 $Ins.\ bonds/liabilities_{it}$, 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 $LCR_i \times Post_t \times Ins.\ bonds/liabilities_{it}$ 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, forthcoming). 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.

4.3 Results

Column 1 in Table 5 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 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 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 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, forthcoming), 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.

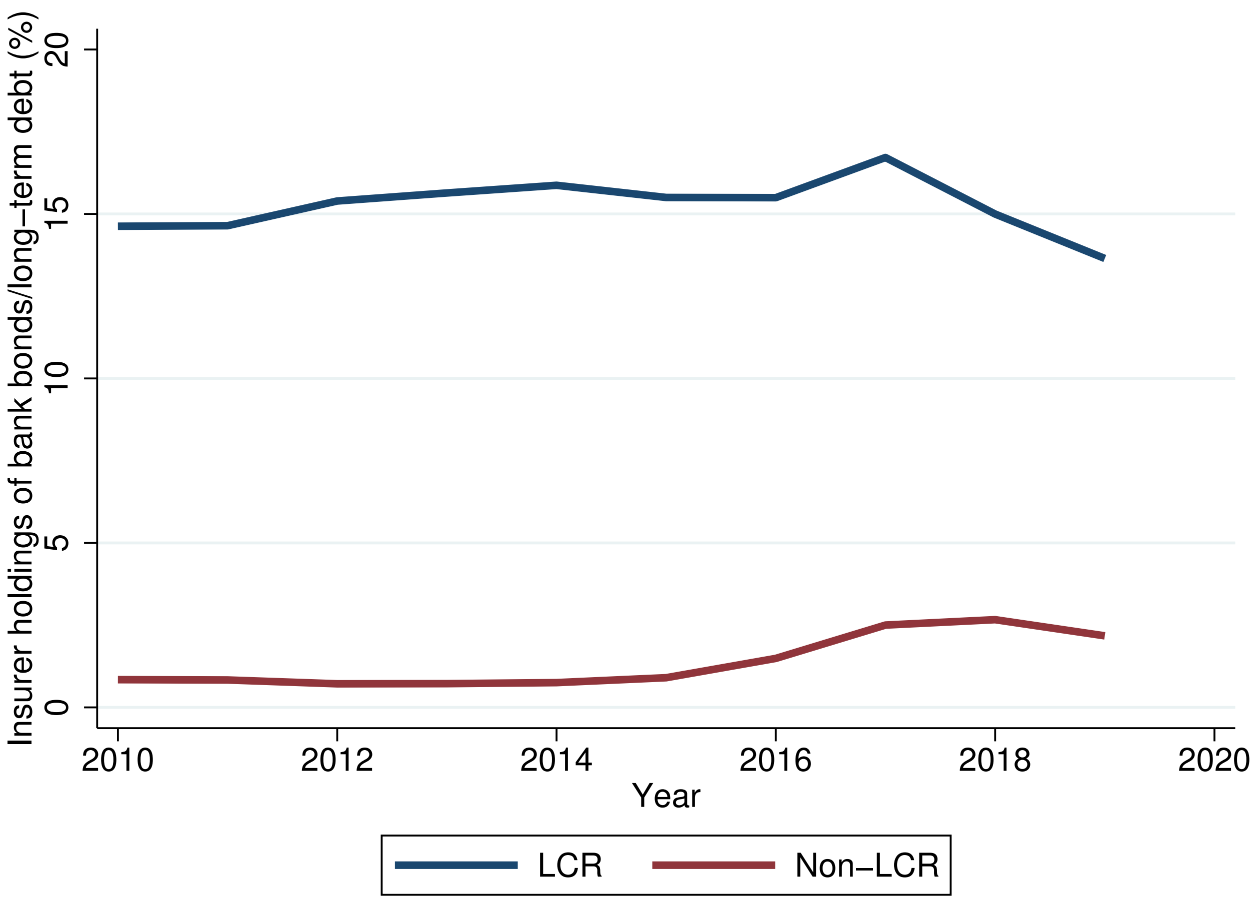

Figure 7: Effect of LCR on Banks' Liquid Assets

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.

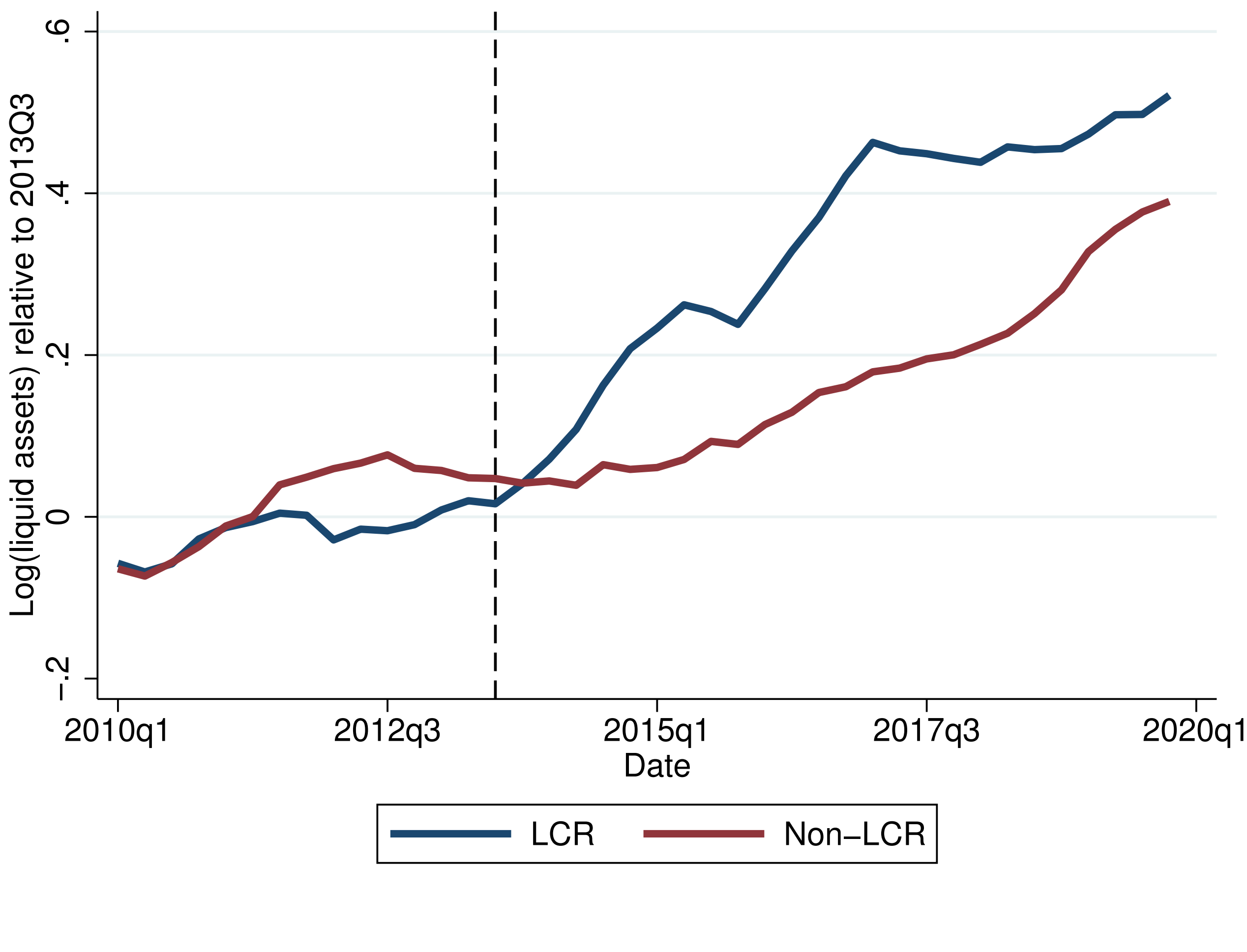

Figure 8: Effect of LCR on Banks' Illiquid Assets

This figure shows the mean ratio 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.

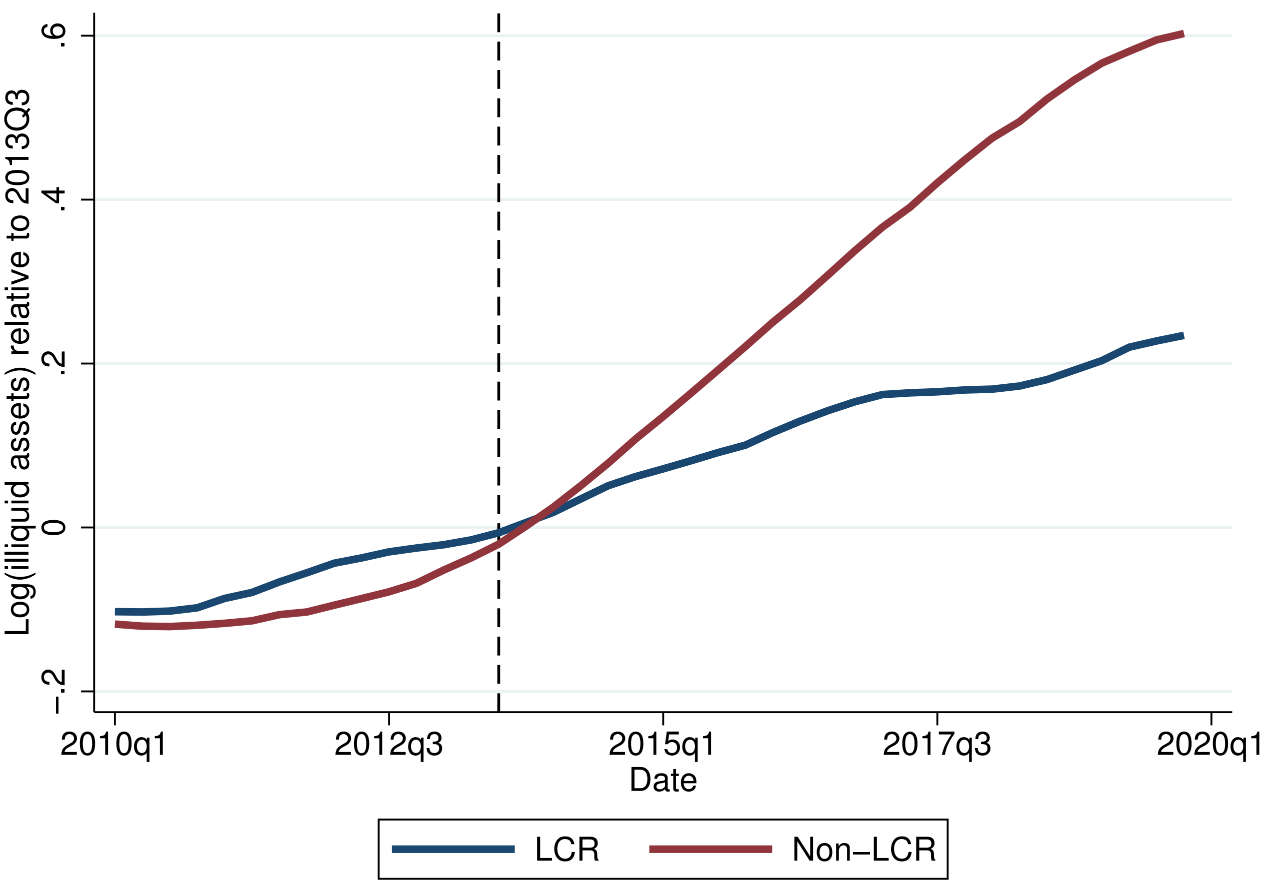

Figure 9: Effect of LCR on Banks' Total Assets

This figure shows the mean ratio 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.

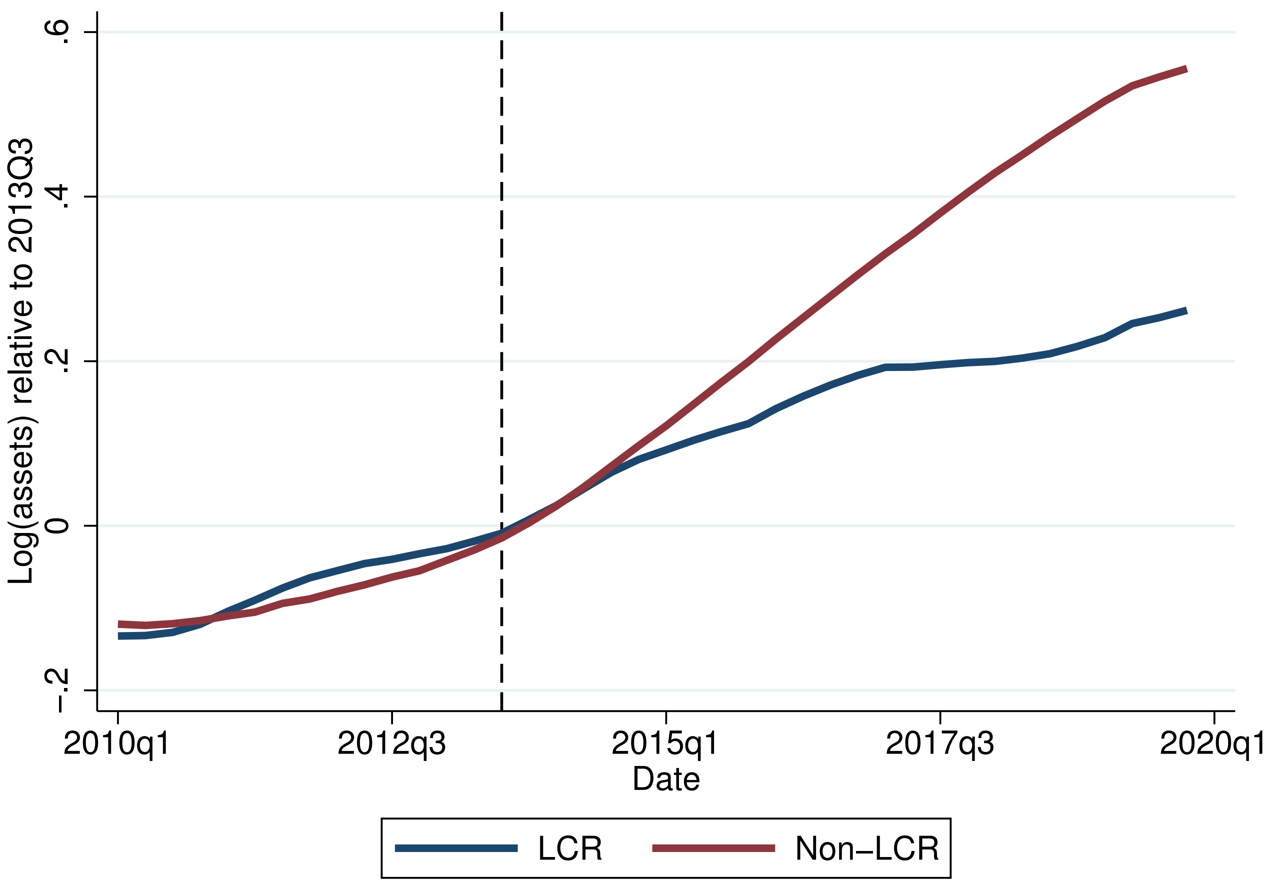

Figure 10: Role of Long-term Funding for Borrowers' Stock-return Volatility among LCR-affected Banks

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.

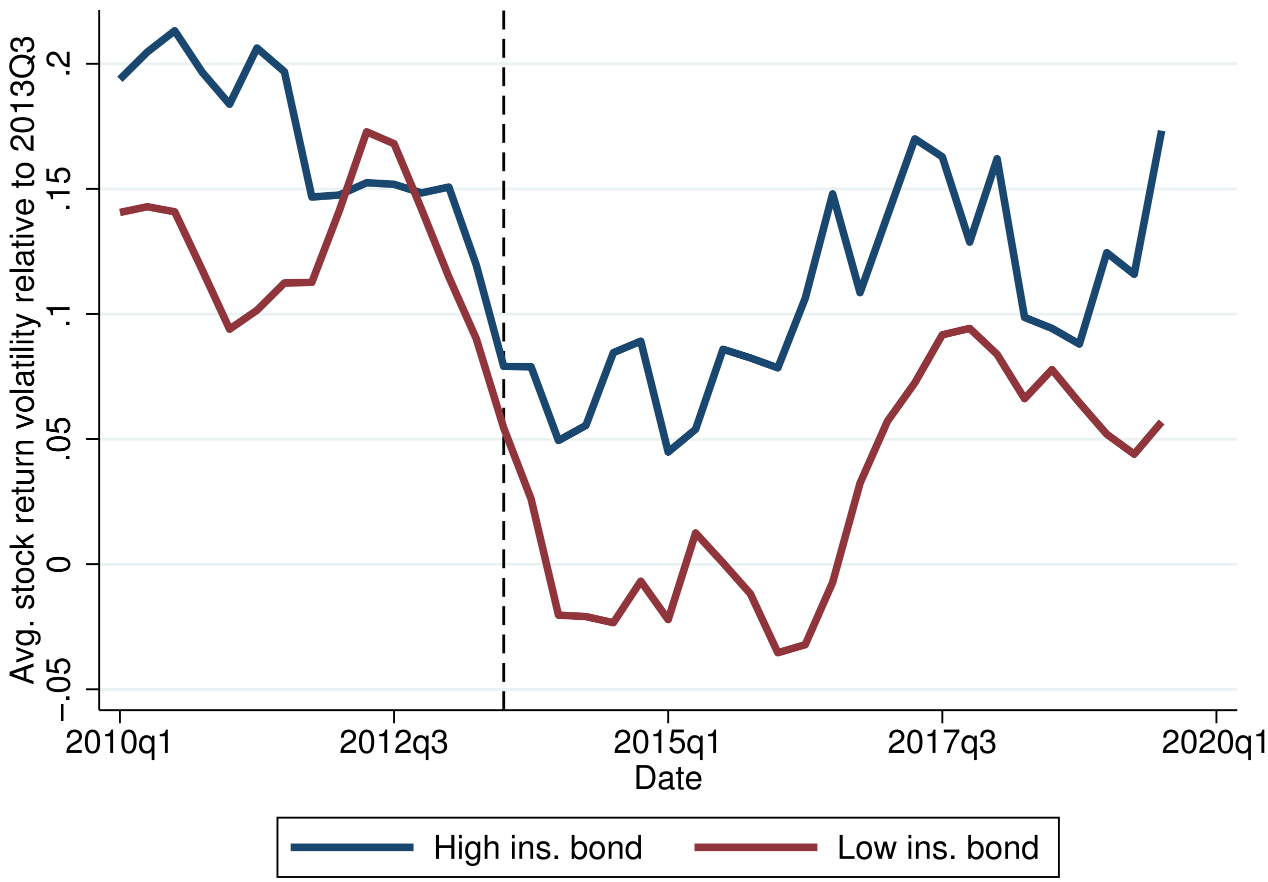

Figure 11: Role of Long-term Funding for Borrowers' Stock-return Volatility among LCR-affected Banks—Robustness to Designation of Insurance Funding

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. *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/long-term debt (%)* is the amount of bonds held by insurance companies at the end of the prior year divided by total long-term debt, expressed as a percentage. *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. *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. *Nonperforming assets/loans (%)* is the ratio of nonperforming 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).

	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
Ins. bonds/liabilities (%)	21,803	0.127	1.108	0.000	42.790
Ins. bonds/long-term debt	19,207	2.250	8.510	0.000	83.198
Average maturity (years)	22,652	1.628	5.474	0.000	49.000
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
Nonperforming 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

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
Ins. bonds/liabilities (%)	0.041	1.231	7.004
Ins. bonds/long-term debt (%)	0.780	15.982	7.243
Average maturity (years)	0.779	15.254	8.252
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

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 where the LCR is interacted 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. *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/long-term debt (%)* is the amount of bonds held by insurance companies at the end of the prior year divided by total long-term debt, expressed as a percentage. *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. *Nonperforming assets/loans (%)* is the bank's ratio of nonperforming 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). *Altman z-score* is the borrower's Altman z-score (Altman, 1968). *Stock-return volatility* is 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
Ins. bonds/liabilities (%)	6,772	0.583	0.479	0.085	3.396
Ins. bonds/long-term debt (%)	6,772	5.884	6.445	1.232	60.582
Average maturity (years)	6,772	10.311	4.926	5.174	30.000
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
Nonperforming 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
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 4.2 with 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 where the LCR indicator is interacted 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.

	(1) Baseline	(2) + controls	(3) + funding	(4) 100% LCR	(5) 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 4.2 with 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 where the LCR is interacted 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.

	(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 4.2 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 where the LCR is interacted 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.

	(1) Baseline	(2) + controls	(3) + funding	(4) 100% LCR	(5) Fix date
LCR × Post	0.268	1.541	22.446**	1.558*	2.154**
	(0.38)	(0.68)	(2.27)	(2.13)	(2.51)
LCR × Post × Ins. bonds/liab.			-26.529**	-1.436**	-2.119**
			(-2.16)	(-2.23)	(-3.21)
LCR × Ins. bonds/liab.			-0.146	-1.019	
			(-0.15)	(-1.08)	
Post × 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

Appendices

A Extensions

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

We maintain analogous parametric restrictions as in the original model (see Section 3.1): $qR_{l,1} < \delta p$, $p < R_{l,1}$, and $\mu > \max\left\{ \frac{1-q}{1-\frac{R_l q}{p}} R_{l,2}, \frac{1}{2} \frac{1-q}{1-\frac{R_l q}{\delta p}} R_{l,2} \right\}$.[12] 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.[13]

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

Proof. See Appendix B. □

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

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

Proof. See Appendix B. □

This result uses the assumptions $R_{l,1} \geq R_{d,1}$ and $R_{l,2} \geq R_{d,2}$. These assumptions ensure that the bank cannot default from liquidity stress if it maintains enough liquid assets to pay all the early 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

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

[13] 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.

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. □

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. 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. 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. □

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

B Omitted Proofs

B.1 Proof of Proposition 1

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

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

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

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 $\mu > \frac{1-q}{1-\frac{q}{p}}R$.

B.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 probability of 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

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

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

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

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:

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

B.3 Proof of Lemma 1

Lemma 1. *The bank's asset choice can be summarized by a threshold μ^* such that it invests in safe assets if $\mu > \mu^*$, and 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 $i = r, s$,[14] 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.

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

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 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

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

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:

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

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:

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

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.

B.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 regulations 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:

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

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

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

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, the probability that liquidity stress causes the bank to default decreases in l. Thus, as l increases, μ^* eventually occurs in case 3, in which case $\frac{d\mu^*}{dl} < 0$. As l increases further, μ^* eventually occurs in case 4, in which case $\frac{d\mu^*}{dl} > 0$. As l increases further such that case 5 occurs, then $\mu^* = \infty$. Therefore $l^*(\lambda)$ 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.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. By Proposition 3 we have $\frac{d\mu^*}{dl} > 0$, and by Proposition 2 we have $\frac{d\gamma_r}{dl} < 0$, which together imply $\frac{dF}{dl} > 0$. It is also straightforward to check that $\frac{d\mu^*}{d\lambda} < 0$

and $\frac{d\gamma_r}{d\lambda} > 0$ and therefore $\frac{dF}{d\lambda} < 0$. By the implicit function theorem, we have

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

B.6 Proof of Proposition 5

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

We first compute the government's expected insurance payout G assuming there is 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 is equal to B, then the government must pay the difference $G = T - B$. We compute government expenditure G for a set of cases depending on l and μ that correspond to the ones introduced in the proof of Lemma 1. Note that the cases depend on the thresholds ζ_i and γ_i, which are defined in the proof of Proposition 2.

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

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

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

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

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

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

G_{D1}.

Case 1C: liquidity stress causes a bank to default in period 2 if it invests in either type of asset ($\zeta_s, \zeta_r < l$ and $\mu < \gamma_s, \gamma_r$)
In this case, for a bank invested in risky assets the expected repayment to investors is

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

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

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

Case 2: liquidity stress causes the bank to default only if it invests in safe assets ($\zeta_s, \zeta_r < l$ and $\gamma_r < \mu < \gamma_s$)
In this case, the bank always prefers risky assets. Therefore, it suffices to compute the government expenditure assuming the bank chooses risky assets. Assuming the bank can remain solvent in the face of liquidity stress if it invests in risky assets, the expected repayment to investors is

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

Denote the government's expenditure in this case by

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

Case 3: liquidity stress causes the bank to default only if it invests in risky assets
There are two subcases depending on whether liquidity stress causes a bank invested in risky assets to default in period 1 or period 2. In either subcase, the bank prefers safe assets if $\mu > \mu^*$ and prefers risky assets if $\mu < \mu^*$, where μ^* is computed in the proof of Lemma 1. If the bank invests in safe assets and can remain solvent in the face of liquidity stress, then the expected repayment to 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. Since the bank can remain solvent in the face of liquidity stress, the expected government expenditure is equal to G_{ND}.

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

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

- Case 4 ($\zeta_s, \zeta_r < l < \lambda$ and $\gamma_r, \gamma_s < \mu^*$): $G = \int_{\mu_{min}}^{\gamma_r} G_{D2} f(\mu) d\mu + \int_{\gamma_r}^{\mu^*} G_{ND} f(\mu) d\mu$

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

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

C Proofs for the Extended Model

C.1 Proof of Proposition 6

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

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

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

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

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

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

C.2 Proof of Proposition 7

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

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

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

Clearly, increasing l always reduces the probability of default in period 1. As for the period 2 default thresholds, if $R_{l,1}l \geq R_{d,1}\lambda$, then the assumptions $R_{l,1} \geq R_{d,1}$ and $R_{l,2} \geq R_{d,2}$ implies:[15]

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

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

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

C.3 Proof of Proposition 8

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

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

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

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

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

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

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

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

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

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

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

Using the assumptions $R_{l,1} > p$ and $R_{d,2} \geq lR_{l,2}$, we have that the effect of tightening liquidity 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:

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

In this case, under the assumption that $\frac{R_{d,2}}{R_{l,2}} \geq \frac{R_{d,1}}{R_{l,1}}$, the effect of tightening liquidity 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 $\mu^*(l;\lambda) = \gamma_r(l;\lambda)$.

C.4 Proof of Proposition 10

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

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

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

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