Capital and Liquidity Interaction in Banking[*]

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Abstract

We study the interaction between banks' capital and their liquidity transformation in both a theoretical and empirical set-up. We first construct a simple model to develop hypotheses which we test empirically. Using a confidential Bank of England dataset that includes bank-specific capital requirement changes since 1989, we find that banks engage in less liquidity transformation when their capital increases. This finding suggests that capital and liquidity requirements are at least to some extent substitutes. By establishing a robust causal relationship, these results can help guide the optimal joint calibration of capital and liquidity requirements and inform macro-prudential policy decisions.

JEL Classification: G21, G28, G32.

Keywords: Banking, Liquidity Transformation, Capital Requirements and Financial Regulation.

1   Introduction

Liquidity played an enormous role in the global financial crisis 2007 - 2009. Many banks experienced difficulties largely because they had not managed their liquidity positions in a prudent manner. In response to this, the Basel Committee on Banking Supervision (BCBS) proposed new regulatory liquidity standards to complement the revised capital framework. Whereas the aim of the capital requirement is to improve bank solvency, liquidity requirements aim to prevent banks aggressively engaging in liquidity transformation, as this can expose them to excessive liquidity risk. The optimal design of these requirements is a non-trivial question. As pointed out by Tirole (2011), it is not clear whether one should append a liquidity measure to the solvency one or whether one should create an entirely different liquidity requirement as was done by the BCBS. To answer this question, we must understand whether these requirements operate as complements or substitutes, but the literature as yet has not been able to answer this question. We aim to shed light on this. By examining the impact of a bank's capital position on its choice of liquidity transformation, we can identify whether higher capital requirements lead to more or less liquidity transformation.

To do this, we construct a simple theoretical model that develops testable hypotheses, and then test these predictions using a unique confidential dataset of UK bank balance sheet data. Our main contribution to the literature is to establish a robust arguably causal relationship. We exploit changes in capital requirements imposed by UK supervisors on UK banks – changes which are arguably exogenous to the banks' liquidity risk profile. We find that capital and liquidity requirements are to some extent substitutes on average over the period studied. By measuring the empirical magnitude of the interaction, our results are useful for understanding the interaction between capital and liquidity regulations, and thereby guiding the optimal future calibration of such requirements. Understanding such interactions is a key priority for policy makers[1].

Our theoretical model is a simple banking model that incorporates a standard maturity mismatch problem.[2] On the liability side, banks are funded by equity and deposits

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[1]See e.g. "Finalising Basel III: Coherence, calibration and complexity", speech by Stefan Ingves (chair of the Basel Committee on Banking Supervision) at the second Conference on Banking Development, Stability and Sustainability, available at http://www.bis.org/speeches/sp161202.pdf.

[2]In general, maturity mismatch is not necessarily equivalent to liquidity mismatch. For example,

that can be withdrawn on demand. On the asset side, banks can invest into either liquid assets or higher yielding, but illiquid assets.[3] If banks cannot meet all withdrawal requests, even after selling all their assets, they will be closed. We refer to a bank's investment in liquid assets as a bank's 'liquidity holdings' and to the situation in which banks face high deposit withdrawals as 'liquidity problems'.

Within the above set-up, we first consider how optimal liquidity holdings differ depending on a bank's capital ratio. We find that the capital ratio has two effects on the choice of liquidity holdings. First, a higher capital ratio means that banks have a more stable liability structure. This in turn implies a lower need for liquidity holdings. This is somewhat a mechanistic impact, but banks can use this to their advantage to shift their portfolio into more higher yielding illiquid assets. Second, a higher capital ratio leads to a higher cost of early liquidation due to insufficient liquidity holdings (i.e. banks lose more in the case of bankruptcy – a *"skin-in-the-game"* effect). This induces banks to hold more liquidity. These two effects trade-off each other, so the overall effect depends on which of the two effects is stronger.

Using a simple numerical analysis, we find that when bank capital is low (i.e. banks are highly leveraged), the *skin-in-the-game effect* dominates. This is because when a bank is highly leveraged, the probability of failure due to liquidity problems is high. As such, any small increase in capital has a big *skin-in-the-game* type impact; since the bank now has to bear more of this high probability of failure. On the other hand, when capital is high, the probability of failing is already relatively low, so any increase in bank capital has little to add in terms of *skin-in-the-game* type incentives. Instead, the bank would predominately see less need for liquidity holdings, so it decreases its liquid asset holdings as the capital ratio rises.

We therefore find an inverted U-shaped relationship between bank capital and liquidity holdings. We take this analysis one-step further by considering how this change in

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financing the purchase of 30-year US Treasuries with overnight repo involves an extreme maturity mismatch but the liquidity mismatch of such a transaction is limited as US Treasuries are typically very liquid. In our model however, to simplify, we assume that the longer the maturity of the asset, the more illiquid it is, which means that maturity transformation and liquidity transformation coincide. Note that our results do not depend on this assumption. All results will still hold as long as illiquid assets are more profitable than liquid assets.

[3]The difference between liquid and illiquid assets is that liquid assets can be converted into cash without any loss in value, while illiquid assets can only be sold at a discounted price.

asset structure interacts with the change in liability structure – since banks are holding more capital. It could be that even though banks decrease their liquidity holdings, since they also hold more capital – they have a more stable liability structure – their overall probability of encountering liquidity problems declines. We explore this in our theoretical framework by considering how a bank's probability of failure following a high deposit withdrawal is affected given changes to both their asset and liability side. Using a numerical analysis, we show that a higher capital ratio leads to an overall lower probability of encountering liquidity problems. Even if banks choose to shed their liquidity holdings, they do not shed them fast enough to offset the benefit of higher capital. Higher capital is therefore consistently associated with lower probabilities of failure due to liquidity.

The model gives us a theoretical prediction on the link between bank capital and incentives to engage in liquidity transformation. We empirically assess this prediction using a confidential dataset that covers the UK's unique capital requirements regime, where firm-level regulatory capital add-ons were set in an arguably exogenous fashion to banks' liquidity risks. This exogeneity allows us to establish causality of the impact from bank capital, with less concern for any reverse causality. By establishing the empirically direction of the effect, our results help us to understand the interaction between capital and liquidity regulations; thereby guiding optimal future calibrations of such requirements. In particular, if better-capitalised banks engage in less liquidity transformation – as hypothesised in our theoretical model – relaxing liquidity and funding requirements could be warranted for a subset of banks or more broadly given the stricter capital requirements in Basel III.[4]

To conduct this empirical test, our analysis uses a measure developed by Berger and Bouwman (2009) as a proxy for the extent to which banks engage in liquidity transformation. This measure, named by Berger and Bouwman (2009) as the "liquidity creation measure", attempts to match the liquidity of banks' assets to the liquidity of their liabilities. In such a way, it generates an index for the extent to which there is a liquidity mismatch between two sides. The degree of liquidity transformation is higher when banks' assets are more illiquid than their liabilities, for example when banks fund mortgages with short-term wholesale funding. Hence, Berger and Bouwman (2009)'s measure constitutes

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[4]See, for instance, Van den Heuvel (2016).

a natural proxy for the level of a bank's liquidity transformation.

Using an unbalanced panel of 154 banks over 1989H2-2013H2, we first find that the data empirically supports the inverted U-shape relationship between between bank capital and liquid holdings. Precisely, in our sample, the turning point is situated around a leverage ratio of 10%. Our empirical result also supports a negative relationship between banks' capital and the overall extent of their liquidity transformation. Moreover, we find that to reduce the degree of liquidity transformation, banks predominately adjust the asset side of their balance sheet by increasing significantly the fraction of bank assets held in the form of liquid assets. Finally, we do not find a significant change in the relationship between capital and liquidity after the crisis in 2007, but we do find a significant difference in the behaviour of small vs. large banks as in Berger and Bouwman (2009).

The rest of the paper is structured as follows. We review the related literature in Section 2. Section 3 sets out the theoretical model and highlights the theoretical predictions on the link between banks' capital and the extent of their liquidity transformation. Section 4 explains the empirical approach and presents the results. Finally, Section 5 concludes.

2 Related Literature

2.1 Theoretical literature

There are two channels through which bank capital can impact a bank's liquidity risk profile. The first channel operates through the role of capital in absorbing losses: the 'loss-absorbing channel'. Since capital acts as a loss absorbing buffer, banks with higher capital ratios should be less vulnerable to runs (from both deposits and short-term wholesale funding). This lower run-risk allows highly capitalised banks to take on greater liquidity risk. This is similar to the role of bank capital in the context of credit risk, as in Repullo (2004) and Allen and Gale (2004).

The second channel is the 'incentive channel'. This works through the incentives a change in bank capital has on a bank's desire to manage its liquidity risk. Gomez and Vo (2019) develop a model where banks control their liquidity risk by managing their liquid

asset positions. They find that banks choose to manage their liquidity risk prudently (i.e. hold a sufficient buffer of liquid assets to be insured against liquidity risk) only when their leverage is low. This is because the lower the bank's capital ratio, the higher the bank's exposure to roll-over risk (i.e. liquidity risk). To insure against this risk, the bank needs to hold a large amount of liquid assets, which is costly since liquid assets are generally less profitable than illiquid ones. As a result, a bank with little capital will find it relatively expensive to insure against this risk, which incentivises the bank to take on greater liquidity risk.[5]

2.2 Empirical literature

The empirical literature on the relationship between capital and liquidity is fairly limited. Distinguin et al. (2013) and Casu et al. (2016) find a negative relationship between capital and liquidity creation using a simultaneous equations model for international and Eurozone banks.[6] More correlational evidence is presented by Bonner and Hilbers (2015), suggesting a negative relationship between capital and liquid asset holdings among international banks. Khan et al. (2017) also suggest that higher capital buffers mitigate the effect of funding liquidity (measured via deposits to total assets) on risk taking.[7] Finally, Sorokina et al. (2017) document that the correlation between US banks' liquidity and capital positions changes sign in recessions.

The most closely related papers to ours are Berger and Bouwman (2009) and De Young et al. (2018). Berger and Bouwman (2009) document that among US banks, more capital is associated with more liquidity creation for large banks, while the relationship is negative for smaller banks. Berger and Bouwman however acknowledge that their study is mainly correlational. While they do attempt to add some robustness via instrumental variables, as is often the case, the validity conditions for the instruments are not obviously satisfied.[8]

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[5]Indeed, the model predicts that below some threshold value, the cost of insurance can be larger than the cost of default meaning the bank takes maximum liquidity risk - i.e. holds no liquid assets. For alternative theories, see also Diamond and Rajan (2000, 2001) and Gorton and Winton (2000).

[6]Horvath et al. (2016) also show that capital reduces liquidity creation in a Granger-causality sense among Czech banks.

[7]They use spreads on non-financial commercial paper as an instrument for funding liquidity (following Acharya and Naqvi (2012)).

[8]In particular, the relevance of the tax rate as an instrument is questionable for large banks operating

DeYoung et al. (2018) also study the interaction between liquidity and capital among US banks and use deviations from inferred firm-specific capital targets for their identification strategy. They find that when the capital level of small banks falls below their target, they engage in less liquidity transformation. For large banks, they find no significant interaction between capital and liquidity transformation.

Our identification strategy is different to both Berger and Bouwman (2009) and DeYoung et al. (2018) since we rely on the exogeneity of capital changes imposed by supervisors in the UK. As such, from a methodological perspective, our paper is related to several studies that have used this specific feature of the UK capital regime to establish causality. These include Aiyar et al. (2014a,b,c), Bahaj and Malherbe (2016), De Marco and Wieladek (2016). All these studies examine the effect of capital requirements on bank lending.[9]

3 Theory

3.1 The model

We consider an economy that lasts for three dates, $t = 0, 1, 2$, and a bank with balance sheet of size normalised to 1. We assume that the bank is funded at date 0 by equity of amount k and retail deposits of amount $1 - k$.[10]

Investment opportunities. The bank has access to two investment opportunities. The first is a short-term asset, referred to as the liquid asset, that produces a gross deterministic return of 1 per period. The second is a constant returns to scale project, which we refer to as the long-term asset. This asset requires a start-up investment at date $t = 0$ and generates a per unit cash flow $R > 1$[11] at date $t = 2$.

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in several states (their measure of marginal tax rate will be more imprecise the more geographically dispersed the bank is). The validity exclusion restriction for the senior citizen instrument is also questionable since the share of seniors might also affect banks' investment opportunities, which in turn may affect their liquidity creation choices.

[9]A conceptually similar strategy using conduct-related provisions is used by Tracey et al. (2016). Tracey et al use conduct-related provisions over a later time period (the regime inducing provisions started in 2010).

[10]Note that since we normalise the size of the balance sheet to 1, k can be interpreted as the bank's capital ratio.

[11]The assumption of deterministic cash flow on the long-term asset allows us to isolate the liquidity channel from any credit risk.

Withdrawal problem. Depositors can withdraw money at date 1. Denote by $\delta \in [0, 1]$ the fraction of deposits that will be withdrawn at date 1. As of date 0, the precise value of δ is unknown to the bank. The bank only knows that δ is distributed according to some distribution $F(.)$. At date 1, the value of δ is known. The bank will need to sell some (or all) of its long-term assets if the withdrawal amount is higher than its liquid asset holdings.

Asset specificity. We assume that due to some kind of asset specificity, potential buyers of the bank's long-term assets are less efficient than the bank in managing them, which implies that these assets will be sold at a unit price lower than their fundamental value R. We further assume that the price discount is increasing in the quantity of assets sold. This can be justified by the fact that the technology used by potential buyers to manage the long-term asset has decreasing returns to scale. Denote by $G(.)$ this technology.

Decision variables. At date 0, the bank has to decide how much to invest in the liquid and long-term illiquid asset. Denote by c its liquid asset holdings.[12] Hence $1 - c$ will be invested in the long-term asset.

Timing. The timing of the model is summarised in Figure 1.

3.2 Analysis

We now analyse the bank's optimal investment decision at date 0. Our main objective is to formulate a prediction on the relationship between a bank's capitalisation and its liquid asset holdings, as well as the probability of incurring withdrawal problems. We proceed via backward induction. First, given liquidity holdings c and the realisation of δ, we determine the unit price of the long-term asset at date 1. Then we examine the bank's optimal liquidity holdings at date 0.

3.2.1 Unit price of the long-term asset

At date 1, given c, the bank will have to sell long-term assets when $\delta(1 - k) > c$. Denote by β and p the fraction of long-term assets the bank needs to sell and the unit

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[12]Note that since we normalise the size of the balance sheet to 1, c can be interpreted as the bank's liquidity ratio.

Date 0	Date 1	Date 2

Given its liability structure$(k, 1 - k)$, bank chooses its liquidity holdings c and its investment $(1 - c)$ in the long-term assets.

- Fraction δ of depositors comes to withdraw.

- Bank repays their depositors by using its liquidity holdings and (possibly) selling long-term assets.

- If the bank cannot raise enough liquidity to repay its depositor, it is liquidated.

- The long-term assets' cash flow is realised.
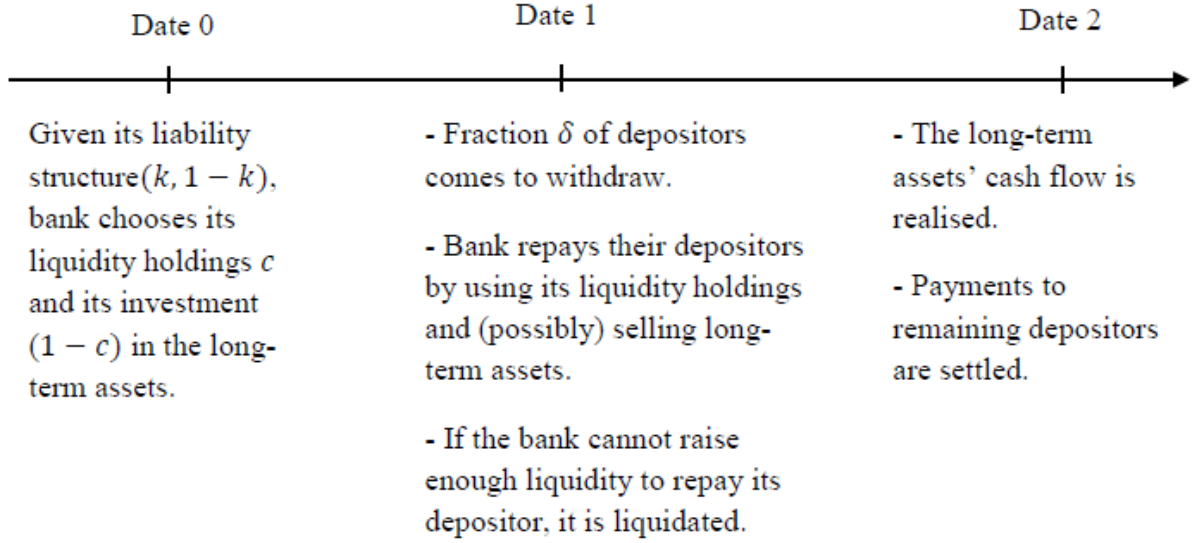
- Payments to remaining depositors are settled.

Figure 1: The timeline

price of this asset, respectively. β and p are determined by two conditions as follows:

$$\beta(1 - c)p \geq \delta(1 - k) - c$$

$$p = G\left[\beta(1 - c)\right]$$

The inequality states that the proceeds from asset sales must cover at least the bank's liquidity demand. The equation specifies that the price is determined by the supply of assets via the technology used by buyers. Combining the above two conditions we see that the unit price is implicitly defined by the following equation:

$$p = G\left[min\left((1 - c), \frac{\delta(1 - k) - c}{p}\right)\right] \tag{1}$$

Denote by $p^e(\delta, k, c)$ the price satisfying Equation (1).

Bank's illiquidity probability. When the fraction of depositors who withdraw at date 1 is very high, the bank cannot raise enough liquidity to repay them even after selling all its long-term asset. In that case the bank is closed and we refer to this situation as the one in which the bank is illiquid.

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Denote by $\overline{\delta}(k,c)$ the cut-off realisation value of δ above which the bank will be closed. Hence, $\overline{\delta}(k,c)$ is determined by the following equation:

$$\frac{\delta(1-k)-c}{(1-c)p^e(\delta,k,c)} = 1 \tag{2}$$

Note that $F\left[\overline{\delta}(k,c)\right]$ is the probability that the bank survives the liquidity problem at date 1. It therefore measures the extent to which the banks' choice of liquidity transformation exposes them to liquidity risk in our model.

3.2.2 Bank's optimal liquidity holdings

We can now solve for the bank's optimal liquidity holdings. The bank will choose c to maximise its expected profits.

Bank's expected profit   At date 0, the bank's expected profit can be written as follows:

$$\Pi = \int_0^{\frac{c}{1-k}} \left[(1-c)R + c - \delta(1-k) - (1-\delta)(1-k)\right] f(\delta)d\delta$$
$$+ \int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \left[(1-\beta)(1-c)R - (1-\delta)(1-k)\right] f(\delta)d\delta \tag{3}$$

The first term is the expected profit the bank will receive if its liquid asset holdings are high enough to cover all withdrawals, i.e. when $\delta \leq \frac{c}{1-k}$. The second term is the bank's expected profit if it cannot cover all withdrawals with its liquid asset holdings and has to sell a fraction of its long-term assets, i.e. when $\frac{c}{1-k} < \delta < \overline{\delta}(k,c)$. When the realised value of δ is greater than the cut-off value $\overline{\delta}(k,c)$, the bank will be closed at date 1 and its profit is equal to zero. After some algebra, we can rewrite the bank's expected profit as follows:

$$\Pi = [R - 1 + k - c(R-1)] - \int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \left[\beta(1-c)(R - p^e)\right] f(\delta)d\delta$$
$$- \int_{\overline{\delta}(k,c)}^1 \left[R - 1 + k - c(R-1)\right] f(\delta)d\delta \tag{4}$$

The bank's expected profit is equal to the expected profit the bank would receive if there is no potential liquidity problem at date 1 minus the expected loss it will incur if its ex-ante liquidity holdings are not sufficient to cover early withdrawals. The second term on the right hand side (RHS) of expression (4) corresponds to the expected loss of selling a fraction of long-term assets at a fire sale price (i.e. at price lower than its fundamental value). The third term corresponds to the expected loss on insolvency when the bank cannot raise enough liquidity to repay withdrawals even if it sells all its long-term asset. It is easy to see that these two terms are decreasing with the bank's ex-ante liquidity holdings c.

Expression (4) also makes clear the trade-off driving the bank's liquidity decision. The cost of holding more liquidity is the foregone return of the long-term asset, which is represented by the term $(-c(R-1))$ in the squared brackets of expression (4). The benefit of holding liquidity thus lies in reducing the expected losses the bank might incur.

Optimal liquidity holdings. The first order condition (FOC) that characterises the bank's optimal liquidity holdings c^* can be written as follows:

$$-\frac{\partial A(k,c^*)}{\partial c} - \frac{\partial B(k,c^*)}{\partial c} = R - 1 \tag{5}$$

where

$$A(k,c) = \int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \left[\beta(1-c)(R-p^e)\right] f(\delta)d\delta$$

and

$$B(k,c) = \int_{\overline{\delta}(k,c)}^{1} \left[R - 1 + k - c(R-1)\right] f(\delta)d\delta$$

Note that, as explained above, $A(k,c)$ and $B(k,c)$ are the two expected losses the bank incurs if withdrawal at date 1 is high enough. As such, the LHS of condition (5) represents the expected marginal profit to the bank of holding liquidity. Condition (5) is the equalisation of the expected marginal benefit to the expected marginal cost of liquidity holdings. After some arrangement, we can rewrite the FOC (5) as follows:

$$\frac{\partial \overline{\delta}(k,c^*)}{\partial c} \left(k - (1-c)(1-p^e)\right) f(\overline{\delta}) + \int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \frac{R-p^e}{p^e} f(\delta)d\delta = \int_{0}^{\overline{\delta}(k,c)} (R-1)f(\delta)d\delta \tag{6}$$

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3.2.3 Bank capitalisation and liquidity holdings

From condition (6), we can see that the capital ratio k affects a bank's liquidity holdings through three channels: (1) through the effect on the illiquidity cut-off $\overline{\delta}(k, c)$; (2) on the equilibrium price p^e; and (3) on the threshold $\frac{c}{1-k}$. The first effect, which we can refer to as a *"skin-in-the-game effect"*, induces the bank to hold more liquidity when it has a higher capital ratio. The last two effects, which we can refer to as a *"liquidity-demand effect"*, instead induce the bank to hold less liquidity when its capital ratio increases. We consider these in turn.

Skin-in-the-game effect. Looking at the third term on the RHS of expression (4), it can be seen that if the bank is closed at date 1, it will lose all its equity. Hence, higher equity induces the bank to reduce its probability of closure at date 1. This is achieved by holding more liquidity, as higher liquidity holdings increase $\overline{\delta}(k, c)$.

Liquidity-demand effect Through the *liquidity-demand effect*, a higher capital ratio induces the bank to hold less liquidity for two reasons. First, higher k will reduce the threshold $\frac{c}{1-k}$ for any given c. Note that this threshold is the level above which liquidity holdings are not sufficient to cover withdrawals. Hence, by increasing one unit of capital, the bank can reduce c while still being able to cover the same level of withdrawals. Second, higher capital k will increase the unit price of the long-term asset p^e, which reduces the loss the bank incurs in the case of selling its long-term asset. This will reduce the benefit of holding liquidity and incentivise the bank to hold less liquidity.

The overall effect of bank capitalisation on its liquidity holdings will depend on which of the above two effects is stronger.

3.2.4 Bank capitalisation and liquidity transformation

The impact of bank capitalisation on liquidity holdings is not the whole story. To complete the picture, we must consider overall survival risk. As explained above, due to the *liquidity demand effect*, banks may decrease their liquid asset holdings when they have higher capital ratios. Nevertheless, this decrease in liquid asset holdings does not necessarily imply an equivalent decrease in survival probability. This is because although it may reduce its liquid asset holdings, it also has more capital and less deposits. This

can be seen in the impact of a bank's capital ratio k on the illiquidity threshold $\bar{\delta}$ that determines the probability the bank is closed due to insufficient liquidity holdings. From Equation (2), using implicit differentiation rule, we get

$$\frac{\partial \bar{\delta}}{\partial k} = \frac{\overbrace{\bar{\delta}}^{\geq 0} + \overbrace{(1-c)\frac{\partial p^e}{\partial k}}^{\geq 0} + \overbrace{(1-p^e)\frac{\partial c}{\partial k}}^{\geq 0 \quad or \quad \leq 0}}{1 - k - \underbrace{(1-c)\frac{\partial p^e}{\partial \delta}}_{\leq 0}} \tag{7}$$

This shows that the bank's capital ratio has three effects. The first effect represented by the term δ in the numerator of expression (7) reflects the impact on the liability structure of the bank. Clearly, the higher the capital ratio is, the more stable the bank's liability structure. This reduces the probability of liquidity problems for any given level of liquid asset holdings. The second effect works through the impact on the price of the long-term asset. Since a higher capital ratio reduces the expected outflow of deposits, it reduces the amount of long-term assets banks need to sell, thus increasing the price. This increase in price improves the market liquidity of the long-term asset.

The third effect arises via the impact of a bank's capital ratio on its liquid asset holdings. From expression (7), we see that if higher capital ratios induce more liquid asset holdings, it will increase the illiquidity threshold and thus increase the probability of survival. However, if higher capital ratios induce banks to hold less liquid assets, the overall effect on survival probability will depend on whether the impact of this reduction is stronger than the two positive effects on price and liability structure.

3.2.5   Numerical example

Unfortunately, FOC (6) can generally not be solved for c in closed form. We therefore consider here a simple numerical example in which δ is uniformly distributed and the technology $G(.)$ of potential buyers takes the form as follows:

$$G(q) = \frac{R}{1+q}$$

Figures 2a and 2b show respectively the bank's optimal liquidity holdings and its

probability of surviving at date 1 as a function of its capital ratio when $R = 1.1$.

Figure 2: Numerical example

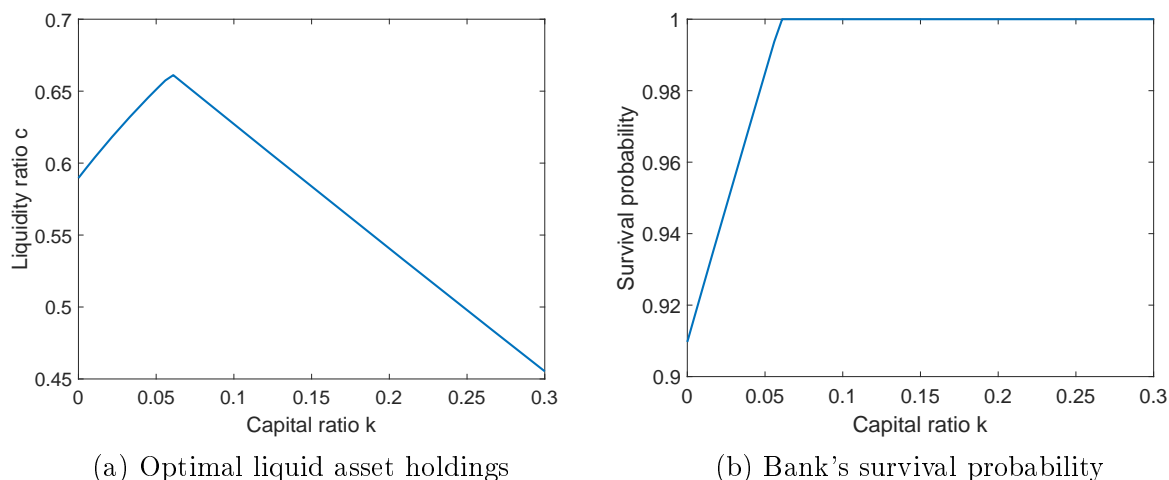(a) Optimal liquid asset holdings

(b) Bank's survival probability

Figure 2a shows that there is a inverted U-shaped relationship between bank capital and liquidity holdings. This is because when k is low enough the *skin-in-the-game effect* dominates, whereas as k increases the *liquidity-demand effect* starts to dominate. This occurs because when k is low enough, the probability of failing at this low level of capital is so high that any small increase in k has big marginal impact on this probability. On the other hand, when k is high enough, the probability of failure is already sufficiently low so increasing k further does not help to improve this probability much. In this situation, once beyond the hump, the bank's optimal liquid asset holdings are decreasing with the bank's capital ratio since liquidity demand decreases.

Figure 2b considers the overall liquidity picture. From this numerical example, we can suggest that higher capital ratios induce banks to engage in overall less liquidity transformation since the probability of survival due to a liquidity shock is increasing in k.[13]

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[13]This result is robust to varying the numerical values for R and to different distributional choices for δ and technology $G(.)$.

4 Empirical strategy and results

4.1 Background on UK regulatory regime

We use bank regulatory data from 1989 to 2013. The key feature throughout this period is that supervisors could impose a requirement in excess of the minimum capital requirement: the Individual Capital Guidance (ICG). A breach of this requirement would then trigger supervisory intervention. Crucially, the supervisor had discretion and could set these requirements at different levels for different banks and change them over time.

Of particular importance to our study is that these add-ons were not set as a function of liquidity risk, or even credit risk. As detailed in Francis and Osborne (2009) *"UK supervisors set ICG [...] based on firm-specific reviews and judgements about, among other things, evolving market conditions as well as the quality of risk management and banks' systems and controls. These triggers are reviewed every 18-36 months, which gives rise to considerable variations in capital adequacy ratios across firms and over time"*. Aiyar et al. (2014b) also show in their empirical analysis that changes in the ICG are not associated with past or future changes in the credit risk of loans.

4.2 Data

4.2.1 Bank balance sheet data

We use the historical regulatory database for the UK banking sector described in De-Ramon, Francis and Milonas (2017). The data is a confidential Bank of England database made from a collation of different reporting templates over three decades, at semi-annual frequency. It covers a period from 1989H2 to 2013H2 and is unbalanced, given that over the period some banks fail, others are bought and new entrants join the market (either new banks or foreign banks opening a subsidiary in the UK). The dataset has information on actual and required levels of capital at the group level (ICG) as well as information on bank balance sheets.

Our sample. Because our database is a collation of different reporting templates over three decades, we have to proceed with caution. To construct our sample, we follow Francis and Osborn (2012) and apply the following filtering criteria to the above dataset.

Firstly, we adjust data for mergers and acquisitions (M&A) identified using Dealogic and information obtained on banks through their annual reporting. To capture material changes that are not encompassed in M&A activity, such as the purchase or divestiture of a business line, we create a new entity when assets falls or rise by more than 30% over 6 months.[14] Second, we drop observations when banks are missing key variables to build our liquidity measures (i.e. total assets, deposits, total capital) and when capital or loans increase or decrease by more than 50% over a half-year. Third, we drop outliers, such as banks with regulatory capital ratios above 50% or below 8%, liquid asset over total asset ratios above 100% or below 0, risk-weighted asset (RWA) densities (RWA over total assets) above 100%. Fourth, to make sure that changes in banks' capital are the result of the changes in the requirements imposed by supervisors, we track every single change in the requirement that is greater than or equal to 5bp of the banks' total risk-weighted assets as in Bahaj and Malherbe (2016). Fifth, to minimise the influence of remaining extreme values, we winsorise our variables at the 1st and 99th percentile. Implementing all those data cleaning steps leads to a sample drop from 3440 data points to 2514.[15] Finally, we conduct the analysis at the highest UK consolidation level for each bank. We keep foreign subsidiaries as well as banks with loans or deposits below 10% of assets. Our final sample is an unbalanced panel composed of 154 banks, with a total of 2514 semi-annual observations.

Table 1 shows summary statistics for the banks in our sample. Our sample is composed of banks of various business models and size. We identified 500 changes in capital requirements in our sample.

Figure 3 illustrates the changes in bank capital requirements over time. There is heightened activity in the late 1990s and early 2000s which largely reflects efforts to improve consistency between different types of firms after the creation of the Financial Services Authority (FSA) in 1997. During and after the financial crisis, ICG has been used more frequently and more broadly, signalling a more pro-active supervisor.

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[14]We exclude banks that have a balance sheet smaller than £500 million, given that small investment banks can grow significantly during 6 months based on the deals they can secure.

[15]The loss of a third of our sample is mainly driven by dropping banks that are missing data required to calculate our liquidity measure and banks with total capital ratios above 50%. In both cases, only very small banks are dropped.

Table 1: Summary statistics

	Observations	Mean	Standard deviation	Min	Max
Total assets (in million £)	2,514	57,426	193,904	22.98	1,435,000
Individual capital guidance (over RWA)	2,514	0.111	0.0250	0.0800	0.193
Actual regulatory capital (over RWA)	2,514	0.184	0.0826	0.0918	0.474
Changes in Individual capital guidance (over RWA)	516	0.000891	0.0158	-0.0564	0.111
RWA density (RWA over total assets)	2,514	0.551	0.203	0.121	0.983
Return on assets	2,514	0.00402	0.00877	-0.0249	0.0454
Net impairments over total loans	2,409	0.00937	0.0222	-0.0146	0.164
liquid assets (broad) to total assets	2,514	0.102	0.110	0	0.634
Derivatives (over total assets)	2,514	0.0184	0.0608	-0.00592	0.675
All loans (over total assets)	2,514	0.521	0.278	0.000115	0.991
Mortgages (over total assets)	2,514	0.201	0.278	0	0.951
Deposits (non-fin.) to total assets	2,514	0.536	0.282	0	0.960
Wholesale debt (over total assets)	2,514	0.325	0.257	0.00249	0.985
Total off-balance sheet commitments (over total assets)	2,514	0.102	0.131	-0.0385	0.851

Note: Data are an unbalanced panel of 154 UK bank with semi-annual observations between 1989H2 and 2013H2.
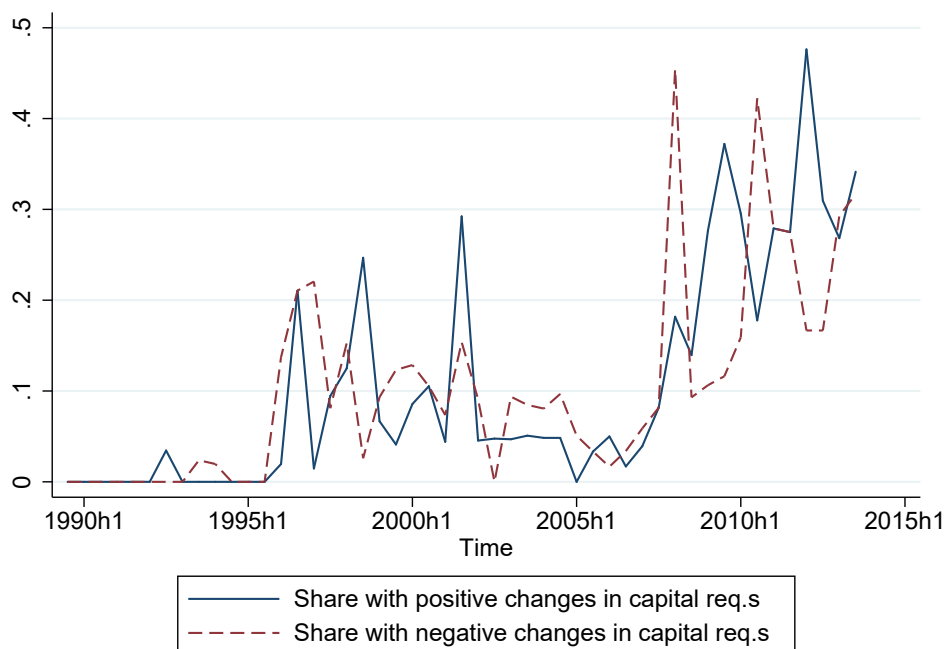

Figure 3: Bank-level capital requirement changes over time

4.2.2 Measure of banks' capital

We exploit the exogeneity of changes in banks' capital requirements imposed by supervisors. We use these requirements as a measure of bank capital. A necessary condition for the validity of this measure is that banks' capital requirements need to affect bank behaviour, which in turn requires that regulatory capital requirements must continuously act as binding constraints on banks' capital ratio choices. Though, binding capital requirements should not be confused with banks always holding capital at the level of the minimum regulatory requirement. Rather, binding capital requirements merely imply that banks adjust their behaviour when the regulatory minimum capital ratio changes. In general, binding capital requirements are perfectly compatible with a voluntary capital buffer chosen to minimise the costs of breaching capital requirements.

For our sample of UK banks, there have been studies examining the extent to which changes in bank-specific capital requirements affect actual capital ratios. These studies find a substantial impact, and all conclude that capital requirements were binding on banks' capital ratio choices. For example, Aiyar et al. (2014c) consider the extent to which capital requirements were binding on bank behaviour, based on the co-movements between weighted capital ratios and weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements that they maintain. For all four groups, the variation in minimum capital requirements were associated with substantial co-movement between minimum requirements and actual capital ratios. This confirmed previous conclusions of Alfon et al (2005), Francis and Osborne (2009), and Bridges et al. (2014) that capital requirements are very often binding on the capital ratio choice for UK banks during this sample period. Figure 4 illustrates this finding in our dataset. We find a significant positive correlation between total capital and the ICG.

4.2.3 Measure of liquidity transformation

We use a variant of the so-called 'liquidity creation' measure developed by Berger and Bouwman (2009), henceforth referred to as the BB liquidity index, as our measure for the extent of banks' liquidity transformation. Since this measure gauges the mismatch
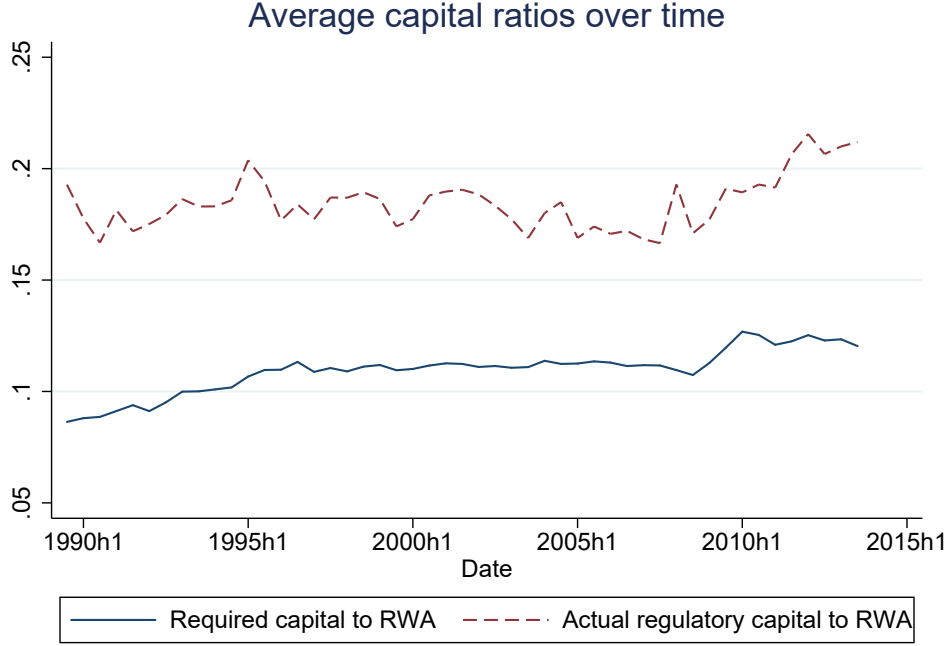
Figure 4: Evolution in actual and required capital ratios

between the liquidity of banks' assets and the liquidity of their liabilities, we believe that it is a better measure for liquidity transformation than measures that look only at the liquidity of either the asset side or liability side. We diverge slightly from Berger and Bouwman (2009) due to data limitations. In particular, we scale the measure to make it comparable between banks and make some changes to the treatment of off-balance-sheet commitments and guarantees. These adjustments are motivated by data limitations and are unlikely to have material impacts.[16]

Our liquidity transformation measure is defined as follows:

$$BB \quad liquidity \quad index = \frac{\sum_i notionalvalue_i \times weight_i}{assets + offBScommitments\&guarantees} \quad (8)$$

where the weights are determined by the classification scheme specified in Table 2. The higher the index is, the more liquidity transformation undertaken by banks.

Berger and Bouwman (2009) classify assets and liabilities into different liquidity buckets based on, for the liability side, the ease, cost and time for banks to meet creditors'

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[16]We control for the treatment of off-balance sheet commitments by also using for robustness a variation of our main measure with the exclusion of off-balance sheet commitments (see Table 7). It does not change our main result.

demand, and, for the asset side, the ease, cost and time to obtain liquid funds. For example, wholesale funding is considered a liquid liability since creditors can choose not to roll over without much cost or time. Alternatively, capital is an illiquid liability since it is nearly impossible for a shareholder to ask the bank to buy back its shares. Loans are considered illiquid since they are difficult to sell on a secondary market, whereas gilts are liquid assets as there exists a large and liquid secondary market for them.

Banks' liquidity transformation is naturally higher if they finance illiquid assets with liquid liabilities as compared to the case in which illiquid assets are funded by semi-liquid liabilities or illiquid liabilities. Consider, for example, two banks. One bank invests in £1000 of loans (an illiquid asset) using £1000 of deposits (a liquid liability), while the other bank invests in liquid assets with illiquid liabilities. Clearly, the first bank is engaging in a much higher level of liquidity transformation than the second bank, which is reflected in their BB liquidity index. Using Formula (8) and the weighting system set out in Table 2, we see that the BB liquidity index of the first bank is equal to 1 while the second bank's index is equal -1. A 'classic' bank with £100 of capital, £900 of deposits as liabilities, £100 of Gilts and £900 of loans as assets, would have a BB liquidity index equal to $\frac{-0.5*100+0.5*900+(-0.5)*100+0.5*900}{1000} = 0.8$. In our sample, as shown in Figure 5, the liquidity index is centred around a mean of 0.5 with a minimum of 0.15 and a maximum of 0.82.

4.3   Econometric methodology

4.3.1   Specification

Using bank-level data, our main regression is:

$$LiqMeasure_{i,t} = \beta_1 + \beta_2 \, CapReqMeasure_{i,t} + \beta_3 \, controls_{i,t-1} + u_i + time_t + \epsilon_{i,t} \quad (9)$$

where i represents a bank and t is the time-period. $LiqMeasure$ is our measure of liquidity transformation - the BB liquidity index - and $CapReqMeasure$ is our measure of capital requirements expressed as a required percentage of capital over total regulatory

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Table 2: Liquidity index

Assets		
Illiquid assets (w = 0.5)	Semi-liquid assets (w = 0)	Liquid assets (w = -0.5)
Loans except residential mortgages	All other assets	Liquid assets

Liabilities plus equity		
Liquid liabilities (w = 0.5)	Semi-liquid liabilities (w = 0)	Illiquid liabilities and equity (w=-0.5)
All liabilities except capital		All capital (regulatory and non-eligible)

Off-balance sheet commitments and guarantees		
All off-balance sheet commitments and guarantees (w=0.5)		

Notes: This table shows the classification of assets and liabilities into different liquidity buckets together with their corresponding liquidity weights. Liquid assets includes high quality liquid assets (cash and balances at central banks, gilts, treasury bills and other highly liquid bills) as well as credit to other financial institutions, debt securities, and equity shares. All off-balance sheet commitments and guarantees includes direct credit substitutes, transaction and trade-related contingents, sale and repurchase agreements, asset sales with recourse, forward asset purchases, forward deposits placed, uncalled party-paid shares and securities, NIFs and RUFs, endorsements of bills, and other commitments
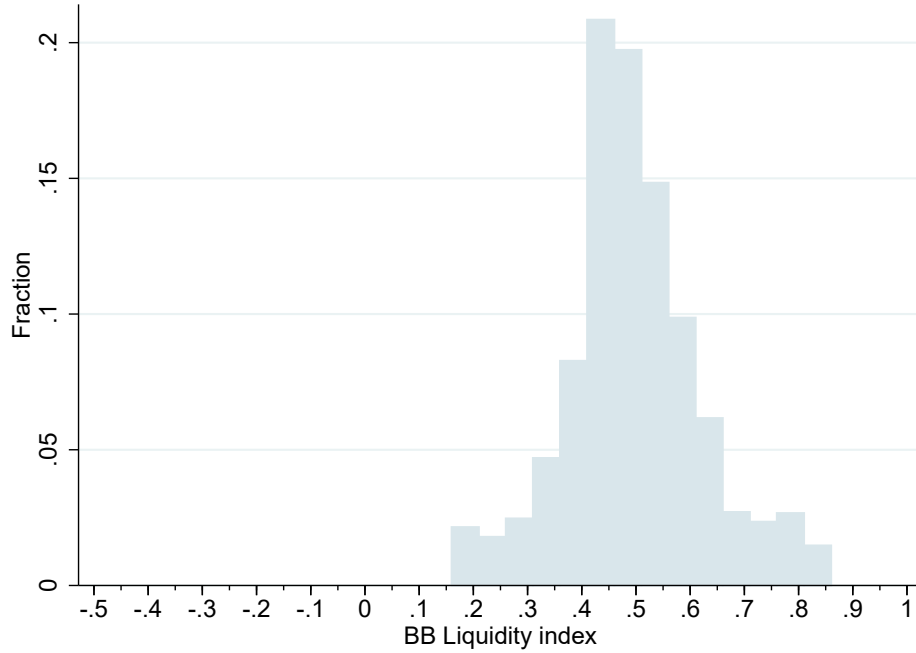
Figure 5: Distribution of the BB liquidity index

RWAs. Based on the literature, we add a set of bank level variables (*controls*) to control for bank specific characteristics: the log of total assets, return on assets, impairments over total loans, RWA density,[17] and the liquidity regime they are subjected to. Controls are lagged by one period to reduce potential endogeneity problems. We estimate the model using fixed effects at the bank level to account for average differences over time across banks that are not captured by other exogenous variables, such as business models, and to reduce correlation across error terms. Time fixed effects are also used to control for the macro environment and for average differences in our liquidity measure across years. All regressions are estimated using robust standard errors, clustered at the bank level. Finally, ϵ is an error term (which might be non-independent between observations).

Control for liquidity regimes. In the period we study, UK banks were also subject to some liquidity requirements as detailed in Appendix A.3. Until 2010, there were three liquidity regimes: the Sterling Stock for the 17 largest firms, the Building society regime for building societies, and the Mismatch regime for all other firms, including subsidiaries of foreign banks. After 2010, the FSA replaced these three liquidity regimes with a

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[17]These four variables are not strongly correlated, thus the inclusion of the four should not create any collinerity problems.

single one, covering all banks (with some exemptions, see Banerjee and Mio, 2017): the Individual Liquid Guidance. We attempt to control for any impact of these regimes on banks' liquidity decisions by including dummies for past liquidity regimes in our regression equation.

4.3.2 Identification

In practice, bank capital and liquidity are to some extent jointly determined. To mitigate this potential endogeneity problem and establish causality, we exploit a specific feature of the UK regulatory regime as described in Section 4.1. Of course, changes in a bank's individual capital requirements were not literally random, but the key condition for a causal interpretation to be valid in our analysis is that these changes in capital requirements imposed by regulators were not driven by changes in banks' liquidity profiles. There are indeed many reasons to believe that banks' liquidity positions were not taken into account in setting these requirements in the period we study.

First, as described in Turner et al. (2009), before the financial crisis, the supervisory approach of the FSA, the previous U.K. regulator, involved more focus on organisational structures, systems and reporting procedures than overall risks in business models. The underlying reason for this focus was the philosophy that the primary responsibility for managing risk lay with the senior management and the boards of individual firms who were better placed to assess business model risk than bank regulators. Regulators would thus focus on making sure that appropriate systems, procedures and skilled people were in place. Bahaj and Malherbe (2017) were able to track some of the confidential letters sent by supervisors to banks notifying them of their new capital guidance, and were able to interview some of the supervisors in charge at that time. They found that supervisors when setting bank capital guidance were: *"focused on bank internal processes rather than the strength of their balance sheet"*.

Second, both FSA reports on the supervision of Northern Rock and on the failure of the Royal Bank of Scotland noted that before the financial crisis, strikingly insufficient weight was given by the FSA to the liquidity profile of banks. For example, Paragraph 164 of the FSA Board Report on the failure of the Royal Bank of Scotland states:[18]

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[18]The report can be found here: https://www.fca.org.uk/publication/corporate/fsa-rbs.pdf

'The Supervision Team commented to the Review Team that analysis of liquidity returns was not a focus of its supervision during the Review Period[19] due, in part, to the limitations of SLR [Sterling Stock Liquidity Ratio]. This was consistent with the findings of The Northern Rock Report which stated that "the analysis by supervisors of regulatory returns, including for liquidity, was consciously de-prioritised..."

Following the crisis, in response to the lessons learned, the FSA made reforms to increase the attention given to the liquidity profile. However liquidity risk was taken into account by changes in liquidity requirements, not capital requirements.[20] Paragraph 200 of the same report highlights that in response to the Turner Review's recommendations on fundamental reforms to the regulation and supervision of liquidity, *"the FSA ... introduced a radically changed liquidity regime, enforced via a more intensive supervisory framework for liquidity"* (Turner, 2009). We argue that after the crisis, individual capital requirements were still rather exogenous to liquidity risks since a whole new liquidity requirement regime was set-up to deal with this risk.

4.4 Empirical results

4.4.1 Inverted U-shaped relation between capital and liquid holdings

One of the predictions of our theoretical model that we can take to the data is the inverted U-shaped relationship between banks' liquid assets holdings and their capital. To test this, we use our measure of capital requirements (i.e. the ICG) over total assets[21] and the three following measures of liquid holdings:

- Narrow liquidity: composed only of high quality liquid assets (HQLA), i.e. cash, central bank reserves and some marketable securities and government bonds.

- Broad liquidity: composed of narrow and less liquid assets (up to level 2B assets in CRDIV, i.e. some covered bonds, corporate debt securities, corporate bonds and

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[19]The Review Period for RBS failure was from the beginning of 2005 to October 2008

[20]See Appendix A.3 for a summary of past liquidity regime in the UK

[21]We employ total assets here instead of RWAs to reflect the fact that in the model, all assets have a weight of one, meaning that the model's predictions are in leverage ratio space. The leverage requirement was not an explicit regulatory requirement. Most ICGs were set as a percentage of RWAs, or sometimes as a raw quantity.

some residential mortgage backed securities.)

- Liquid assets: based on assets classified as liquid in the BB liquidity index.

In Table 3 we find a negative and statistically significant coefficient for the squared term of the capital requirement indicating an inverted U-shaped relationship with the three measures of liquidity. To find the turning point, we take the derivative of our regressions equations.[22] We plot the derivatives of our three specifications in appendix A.4. The turning point of the three estimations is situated around a leverage ratio of 10%.

This result seems to confirm the predictions of our model. It implies that banks with an implicit leverage ratio requirement above 10% tend to reduce their liquid assets holding for each increase of their implicit leverage ratio requirement. We observe that those banks have riskier assets (the average RWA is 86% compared to 55% for our total sample), they seem to have less deposits (34% instead of 54%), and a bit more wholesale debt (38% instead of 32%).

Given that the threshold we identified is rather high compared to the current leverage ratio requirement (at 3%) and actual banks' leverage ratios (on average around 4-5% for large UK banks), most of the UK banking system is not in this area where they would reduce their liquid assets after an increase in capital. We find that only 10% of our observations, and 27 banks that are quite small[23] have a leverage ratio above 10%.

4.4.2 Bank capital and liquidity transformation

Our main regression results on the link between banks' capitalisation and the extent in which they engage in liquidity transformation are presented in Table 4. In the first column we find that higher capital ratios induce banks to reduce their liquidity transformation. This is in line with the literature. To interpret the magnitude of the coefficient, it is important to remember that our measure of capital is in percentage terms while our liquidity index is scaled between -1 and 1. Based on Equation (8) and the first column

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[22]We include a square term for capital in equation 9: $LiqMeasure_{i,t} = \beta_1 + \beta_2\,CapReqMeasure_{i,t} + \gamma\,CapReqMeasure_{i,t}^2 + \beta_3\,controls_{i,t-1} + u_i + time_t + \epsilon_{i,t}$, so the derivative is: $\beta_2 + 2\,\gamma\,CapReqMeasure$

[23]The largest being three times smaller than the average size bank for the whole sample.

Table 3: Relation between liquid asset holdings and capital

VARIABLES	(1) Liquid assets (BB)	(2) Broad	(3) Narrow
Capital req. (to total assets)	2.343*	2.668**	1.212**
	(1.210)	(1.172)	(0.474)
Capital req. squared (to total assets)	-11.86**	-13.63**	-6.205**
	(5.489)	(5.430)	(2.438)
RWA density (lagged)	-0.0691	-0.0799	-0.0335
	(0.0648)	(0.0684)	(0.0263)
ROA (lagged)	-0.294	-0.312	-0.299
	(0.309)	(0.321)	(0.203)
Impairment scaled (lagged)	-0.262**	-0.369***	-0.0593
	(0.114)	(0.142)	(0.0658)
Total assets (lagged and log)	0.0246	0.0240	-0.00727
	(0.0185)	(0.0194)	(0.00912)
Constant	-0.120	-0.138	0.0832
	(0.168)	(0.178)	(0.0777)
Methodology	FE	FE	FE
Liquidity regimes	YES	YES	YES
Observations	1,984	1,984	1,984
Adj. R2	0.759	0.726	0.751
Adj. R2 within	0.0466	0.0746	0.0715
Banks	154	154	154

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: This table shows our regression results for the inverted U-shaped relationship between banks' liquid assets holdings and their capital. In column (1), we use assets classified as liquid in the BB liquidity index as the measure of the banks' liquid asset holdings. Column (2) shows the regression results when we use a broad measure of liquid assets that is composed of high quality liquid assets (HQLA) and less liquid assets (up to level 2B assets in CRD IV). Column (3) displays the regression results when only HQLA is counted as liquid assets. The main regressor is our measure of capital requirement (ICG) over total assets.

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in Table 4, we find that an increase of 1% in the risk-weighted capital requirement will induce a decrease of 1.046% in our liquidity index.

To adjust their risk-weighted capital ratio, banks can shift their portfolio towards assets with a lower risk-weight. Those assets, for example government bonds, are also more liquid. To control for this portfolio rebalancing we include the RWA density - i.e. RWA over total assets - in the regression reported in the second column. The coefficient on the RWA density is positive and significant. When banks have a riskier portfolio (as measured by greater risk-weights), they engage in more liquidity transformation. The magnitude of the coefficient of our capital requirement variable is reduced a little, but stays significant, implying that the capital requirement has an effect on liquidity transformation beyond portfolio rebalancing towards assets with lower risk-weights, but also through the increased amount of capital. This is in line with the *skin-in-the-game effect* described in the theoretical model. Finally, in the last three columns of Table 4, we explore the long term effect of the capital guidance. We find that, up to the third lag (ie. 1.5 year) the effect is rather persistent and tend to increase.

4.4.3 Banks' balance sheet adjustments

Our main result suggests that an increase in the level of capital induces banks to engage in less liquidity transformation. To understand what adjustments banks make to reduce the extent of their liquidity transformation, we examine in Table 5 the relationship between banks' capital requirements and the different components of their balance sheet. To do so, we adapt our main regression specification given in equation 9 and replace the dependent variables by the six main unweighted components of the BB liquidity index: liquid assets, semi-liquid assets, illiquid assets, deposits, wholesale funding and off-balance sheet. These variables are measured as ratios over total assets.

The first observation is that banks only adjust through the asset side. The share of bank assets held in the form of liquid assets increases, while illiquid assets have a negative and significant coefficient. This suggests that following an increase in capital requirements, banks adjust their liquidity transformation by rebalancing their portfolio towards more liquid assets (e.g. cash or gilts) perhaps, as suggested in Francis and Osborne (2012), by not renewing some of of their loans.

Table 4: Main results

VARIABLES	(1)	(2)	(3)	(4)	(5)
Capital req.$_t$	-1.046***	-0.804**			
	(0.306)	(0.336)			
Capital req.$_{t-1}$			-0.879**		
			(0.378)		
Capital req.$_{t-2}$				-0.947**	
				(0.363)	
Capital req.$_{t-3}$					-1.010**
					(0.387)
RWA density		0.177***	0.163***	0.128**	0.0930*
		(0.0509)	(0.0510)	(0.0496)	(0.0522)
ROA	-0.0446	-0.134	-0.219	-0.342	-0.221
	(0.241)	(0.253)	(0.312)	(0.316)	(0.467)
Impairment scaled	0.233**	0.198**	0.0814	0.0267	0.0301
	(0.0964)	(0.0900)	(0.101)	(0.123)	(0.129)
Total assets (log)	0.00442	0.0178	0.0127	0.00575	-0.00679
	(0.0134)	(0.0129)	(0.0125)	(0.0133)	(0.0168)
Constant	0.575***	0.345***	0.405***	0.491***	0.623***
	(0.110)	(0.116)	(0.111)	(0.117)	(0.147)
Methodology	FE	FE	FE	FE	FE
Liquidity regimes	YES	YES	YES	YES	YES
Observations	2,000	2,000	1,736	1,598	1,471
Adj. R2	0.860	0.869	0.875	0.872	0.863
Adj. R2 within	0.0701	0.130	0.121	0.0991	0.0787
Banks	154	154	134	123	113

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table shows our regression results on the link between banks' capitalisation and their liquidity transformation. The dependent variable is our measure of capital requirements. The main regressor is our measure of capital requirements expressed as a required percentage of capital over total regulatory RWAs. The regression specification is given in Equation (9). All control variables have one extra lag compare to our capital measure. For example, when our capital measure is lagged twice, the control variable ROA is lagged three time.

Table 5: Banks adjustments

VARIABLES	(1) liquid assets	(2) semi-liquid assets	(3) illiquid assets	(4) deposits	(5) wholesale funding	(6) off-balance sheet
Capital req.$_t$	0.587*	0.291	-0.835*	-0.455	0.400	-0.0472
	(0.308)	(0.412)	(0.443)	(0.700)	(0.638)	(0.252)
RWA density$_{t-1}$	0.0334	-0.590***	0.513***	-0.139	0.0318	0.0448
	(0.0607)	(0.109)	(0.0572)	(0.137)	(0.104)	(0.0659)
ROA$_{t-1}$	-0.101	-1.116*	0.924	-1.045	0.0848	0.314
	(0.297)	(0.613)	(0.724)	(1.248)	(1.051)	(0.391)
Impairment scaled$_{t-1}$	-0.277**	0.189	0.0425	0.305	-0.293	0.0467
	(0.109)	(0.155)	(0.142)	(0.427)	(0.409)	(0.141)
Total assets$_{t-1}$(log)	0.0282	-0.0169	0.00107	0.00637	0.0381	-0.0122
	(0.0177)	(0.0238)	(0.0203)	(0.0448)	(0.0396)	(0.0183)
Constant	-0.194	0.889***	0.0996	0.573	-0.0849	0.201
	(0.162)	(0.242)	(0.203)	(0.456)	(0.383)	(0.190)
Methodology	FE	FE	FE	FE	FE	FE
Liquidity regimes	YES	YES	YES	YES	YES	YES
Observations	2,000	2,000	2,000	2,000	2,000	2,000
Adj. R2	0.751	0.928	0.933	0.891	0.879	0.836
Adj. R2 within	0.0456	0.256	0.291	0.0419	0.0220	0.0242
Banks	154	154	154	154	154	154

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table shows our regression results on how banks adjust to decrease their liquidity transformation. The dependent variables shown in Column (1) to Column (6) are respectively the six main unweighted components of the BB liquidity index: liquid assets, semi-liquid assets, illiquid assets, deposits, wholesale funding and off-balance sheet. These variables are measured as ratios over total assets. The main regressor is our measure of capital requirements expressed as a required percentage of capital over total regulatory RWAs.

On the liability side, we do not find statistically significant coefficients to suggest that following an increase in capital requirements, banks alter the composition of their liabilities. This could be explained by the fact that banks have far less flexibility to adjust their liability side and therefore they may adjust it over a longer time horizon.

4.4.4   Main drivers

To explore the drivers of the relationship between banks' capital and their liquidity transformation, we further decompose the coefficient β_2 in Equation (9) using a relevant dummy variable Z, where we are interested in pre- versus post-crisis, and large versus small banks:

$$\beta_2 = \beta_3 + \beta_4 \ Z_{i,t} \tag{10}$$

We thus estimate the following equation:

$$LiqMeasure_{i,t} = \beta_1 + (\beta_3 + \beta_4 \ Z_{i,t}) * \ CapReqMeasure_{i,t} + \beta_5 \ Z_{i,t} + \beta_6 \ controls_{i,t-1}$$
$$+u_i + time_t + \epsilon_{i,t}, \tag{11}$$

where Z is a dummy variable based on whether a bank is large or small respectively; or the time period is pre- or post-crisis respectively in the alternative specification.

This equation investigates if the effect of capital on banks' choice of liquidity transformation varies across the variable Z. Our focus is on bank size and the crisis period. Precisely, in the first specification, the dummy variable takes the value 1 for the ten largest banks in our sample, 0 otherwise. In the second specification, the dummy variable takes the value 1 for the period before the crisis (up to and including 2006), 0 otherwise.

The results are shown in Table 6. In the first column we introduce the dummy variable that takes the value of 1 for years before 2007 and 0 otherwise. The coefficient on the variable capital requirement does not change compared to our main regression shown in Table 4. Moreover, the coefficient on the interaction is not statistically significant. This suggests that the relationship between bank capital and liquidity transformation is not

Table 6: Drivers

VARIABLES	(1) Crisis	(2) 10 largest banks
Capital req.$_t$	-0.767***	-0.956***
	(0.274)	(0.354)
Capital req.$_t * I_{year<2007}$	-0.0799	
	(0.395)	
Capital req.$_t * I_{top10banks}$		1.853**
		(0.880)
RWA density$_{t-1}$	0.178***	0.167***
	(0.0501)	(0.0502)
ROA$_{t-1}$	-0.132	-0.202
	(0.253)	(0.276)
Impairment scaled$_{t-1}$	0.200**	0.212**
	(0.0885)	(0.0880)
Total assets$_{t-1}(log)$	0.0180	
	(0.0130)	
Constant	0.347***	0.478***
	(0.118)	(0.0552)
Methodology	FE	FE
Liquidity regimes	YES	YES
Observations	2,000	2,000
Adj. R2	0.869	0.871
Adj. R2 within	0.130	0.140
Banks	154	154

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table shows our regression results on the main drivers of the relationship between banks' capital and their liquidity transformation. In Column (1), we display the results when we interact our main capital requirement measure with a dummy variable that takes the value of 1 for years before 2007 and 0 otherwise. In Column (2), we present the results when the capital requirement measure is interacted with a dummy that take the value of 1 if banks are among ten largest banks in our sample.

significantly different in the period after 2007 compared to the period before the crisis. Though, the effect of capital before the crisis (i.e. the sum of the coefficient of the capital requirement and the interaction term) is 0.85 and is significant at the 10% level. The negative relationship between capital and liquidity seems to persist after the crisis and our results do not suggest any significant change in this relationship over time: the 2007-08 financial crisis does not seem to have been a structural changer in this relationship, which could suggest that the negative relationship is rooted in the bank business model.

In the second column we introduce a dummy variable that takes the value 1 for the ten largest banks in our sample, 0 otherwise. The coefficient on our capital requirement variable is still negative and of the same magnitude as the one in our main regression, but the coefficient on the interaction term is significant and positive. It indeed suggests that the largest banks have a different (positive) coefficient compared to small banks. This is consistent with the finding of Berger and Bouwman (2009). Though, when we calculate the total effect of capital on liquidity transformation for large banks as in Equation 10, we find a coefficient of 0.85, with a p-value of 0.3. It follows then that for the ten largest banks in our sample, the relationship between capital and liquidity is significantly different from the rest of the sample, but it does not seem to be statistically significantly different from zero.

4.4.5 Robustness

Our main results hold with alternative versions of the liquidity index and using pooled OLS. This is shown in Table 7. In the first column, using pooled OLS – which does not account for bank heterogeneity, but has better efficiency – we find similar results and a slightly larger coefficient. In the second column, we remove capital from our liquidity measure, as in Berger and Bouwman (2009). This is to make sure that our results are not driven by the fact that capital ends up on both side of the equation, even if they are not exactly the same measures of capital (we use individual capital guidance in the dependent variable, while we use total capital to build our liquidity measure). The results still hold.

Finally, in the third column, we remove off-balance sheet assets from the BB liquidity index, as in Berger and Bouwman (2009). We do this to separate off-balance sheet activity from core traditional banking activities (lending and on-balance sheet market activity),

Table 7: Robustness

VARIABLES	(1) OLS	(2) Excluding capital	(3) Excluding off-balance sheet
Capital req.	-1.215***	-0.915**	-0.881**
	(0.363)	(0.433)	(0.362)
RWA density (lagged)	0.396***	0.270***	0.224***
	(0.0405)	(0.0504)	(0.0563)
ROA (lagged)	-1.492	0.842	-0.179
	(0.992)	(0.682)	(0.295)
Impairment scaled (lagged)	0.208	0.161	0.236**
	(0.280)	(0.119)	(0.111)
Total assets (lagged and log)	-0.00541	-0.0269	0.0164
	(0.00344)	(0.0200)	(0.0143)
Constant	0.474***	0.778***	0.364***
	(0.0651)	(0.195)	(0.127)
Methodology	OLS	FE	FE
Liquidity regimes	YES	YES	YES
Observations	2,030	2,000	2,000
Adj. R2	0.494	0.898	0.861
Adj. R2 within		0.198	0.148
Banks	184	154	154

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: This table shows our robustness results. Column (1) display the results when we use pooled OLS. In Column (2), we present the results when we remove capital from our BB liquidity index computation. In Column (3) we show the results when the off-balance sheet items are removed from the BB liquidity index.

and to check if our results hold without off-balance sheet exposures for which we have less granularity. Given that the magnitude of the coefficient on our capital measure is unaffected – it is still statistically significant and negative – it seems that for UK banks, liquidity transformation occurs mainly via on-balance sheet activities.

5 Conclusions

In this paper, we examine the link between bank capital and liquidity transformation. We first derive, in a simple theoretical model, predictions on the relationship between banks' capital and their liquidity holdings as well as the extent this effects their overall liquidity transformation and therefore their probability of surviving a liquidity shock. We find an inverted U-shaped relationship between bank capital and their liquid asset holdings, but we find that bank capital increases the probability of surviving a liquidity shock since any decrease in liquid asset holdings is not sufficient to outweigh the increase in capital. Our empirical results support these predictions, and in line with the literature suggest that banks engage in less liquidity transformation when they are better capitalised. Considering the mechanics behind this adjustment, we find that banks will mainly adjust their liquid asset holdings. We do not find a significant change in the relationship between capital and liquidity after the 2007-08 financial crisis, but we do find a statistically significant difference in the behaviour of small and large banks. It might be a helpful insight for the debate on simplifying regulatory requirements for small banks.

The results suggest that capital and liquidity requirements are to at least some extent substitutes. Increasing the capital requirement will in general lead banks to engage in less liquidity transformation, regardless of the liquidity requirement. However, it does not mean these requirements are always substitutes. In a period of high liquidity stress, when uncertainty is high and the value of assets is particularly uncertain, a bank's level of capital matters less as liquidity risk increases sharply. In this case, capital and liquidity requirements should act in a more complementary fashion.

A Appendix

A.1 Derivation of the impact of capital on the failure threshold

In the equilibrium, Equation 2 can be rewritten as follows:

$$\frac{\overline{\delta}(1-k) - c(k)}{[1 - c(k)]\, p^e(\overline{\delta}, k, c(k))} = 1 \tag{12}$$

where the dependence of c on k is written explicitly. This equation is equivalent to the following:

$$\overline{\delta}(1-k) - c(k) - [1 - c(k)]\, p^e(\overline{\delta}, k, c(k)) = 0 \tag{13}$$

Now using the implicit differentiation we get:

$$\frac{d\overline{\delta}}{dk} = -\frac{-\overline{\delta} - \frac{\partial c}{\partial k} p^e + \frac{\partial c}{\partial k} - (1 - c(k))\frac{\partial p^e}{\partial k}}{1 - k - (1 - c(k))\frac{\partial p^e}{\partial \delta}} \tag{14}$$

After some rearrangement, we have

$$\frac{d\overline{\delta}}{dk} = \frac{\overline{\delta} + (1 - c)\frac{\partial p^e}{\partial k} + (1 - p^e)\frac{\partial c}{\partial k}}{1 - k - (1 - c)\frac{\partial p^e}{\partial \delta}} \tag{15}$$

A.2 Distribution of changes in capital requirements

This histogram plots the distribution of the size of changes in capital requirements as part of the Individual Capital Guidance regulatory regime. For 60% of the cases, new capital guidance are below 1%, are there are very few cases of changes in the ICG greater than 4%.
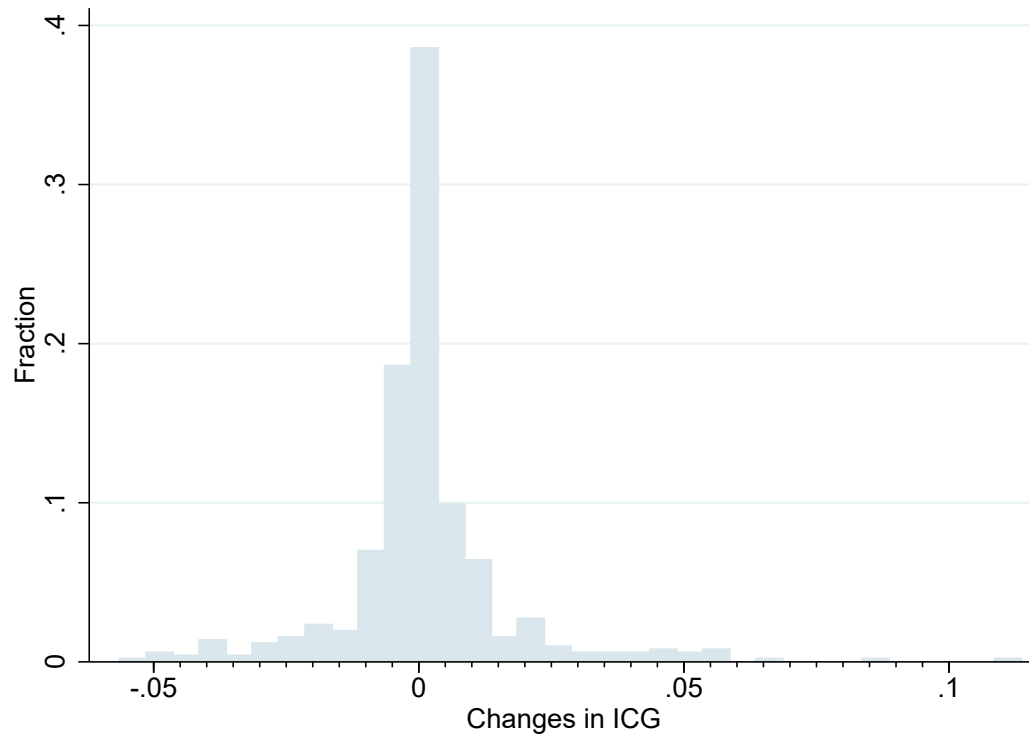

Figure 6: Distribution of changes in capital requirements

A.3 Past liquidity regimes in the UK

This table summarises the different liquidity regimes in the UK for our sample. Liquidity regimes in the UK before the ILG were light touch and very rarely binding for banks.

| Time period	Pre-2010		Post-2010	
Regime name	Sterling stock regime (started in 1996)	Mismatch liquidity regime	Building society regime	Individual Liquidity Guidance (ILG)
Coverage	Major sterling clearing banks	Other banks	Building societies	All banks in principle, though waivers and modifications given
Requirements	Stock of eligible assets to meet wholesale sterling outflows over the next five days and cover 5% of maturing retail deposits withdrawable over the same period. Allowable certificates of deposit could partly be used to offset wholesale sterling liabilities.	Liquid assets to cover outflows in worst-case scenarios over specific time horizons.	Liquid assets covering 3.5% of liabilities.	Firm-specific minimum ratio of liquid assets to net stressed outflows over 2 week- and 3 month horizons.

A.4   Total effect of capital on liquid assets
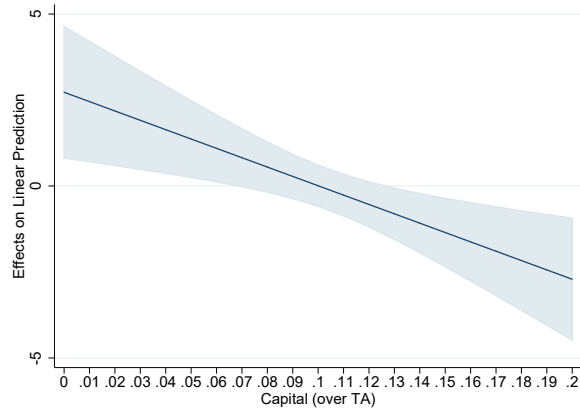
(a) Liquid assets (BB)
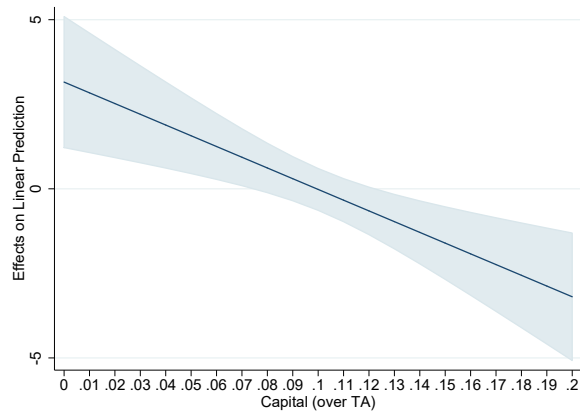
(b) Broad liquid assets
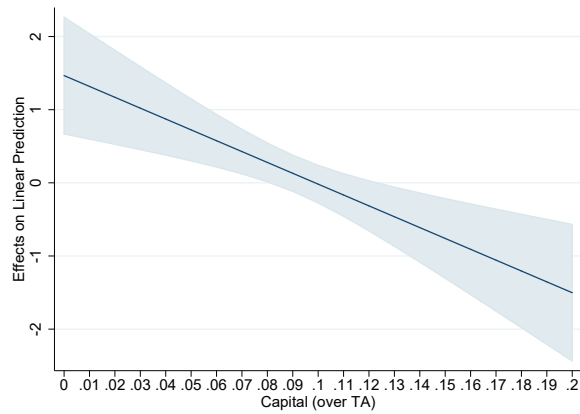
(c) Narrow liquid assets

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