Bank capital and liquidity transformation *

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Abstract

We study the interaction between bank capital and liquidity transformation in both a theoretical and empirical setup. Do banks with greater amounts of capital engage in more or less liquidity transformation? We answer this question empirically using a confidential Bank of England dataset that includes all bank-specific capital requirement changes since 1989. We find that banks engage in less liquidity transformation when they have higher capital. 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 calibration of capital and liquidity requirements and help calibrate macroprudential policy.

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1 Introduction

Liquidity played an enormous role in the recent global financial crisis. Many banks experienced difficulties largely because they had not managed their liquidity in a prudent manner. In response to these flaws, the Basel Committee on Banking Supervision (BCBS) proposed two regulatory liquidity standards to complement the revised capital requirement framework. Whereas the aim of the capital requirement is to increase bank solvency, the liquidity requirements aim to promote better liquidity risk management. This immediately raised a key question as pointed out by Tirole (2011): '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, one must understand whether these requirements operate as complements or substitutes. So far, evidence in either direction is lacking. This paper aims to fill this gap using a positive approach. We examine the impact capital has on banks' incentives to manage liquidity more prudently. We first construct a simple theoretical model to develop testable hypotheses. We then test our predictions using a unique confidential dataset of UK bank balance sheet data and supervisory capital requirement changes.

Our theoretical model is a standard maturity mismatch problem. Banks invest some funds into liquid assets in order to deal with depositor withdrawals, the rest in higher yielding assets. We first consider how the optimal liquidity holdings differ depending on capital ratios. 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, which in turn implies a lower need for liquidity. This is somewhat a mechanical 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 the bank is highly leveraged, the probability of liquidity problems is high. As such, any small increase in capital has a big 'skin-in-the-game' type impact as 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 and so any increase in bank capital does not bring about the same shift in incentives. Instead, in this case, the bank sees less need for liquidity and so 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 to consider how the change in asset structure described above interacts with the change in liability structure – since banks are holding more capital. Even if banks decrease their liquidity holdings, since with more capital, they have a more stable liability structure, it can be that the overall liquidity risk profile declines. We explore this in our theoretical framework by considering how the probability of failure (due to liquidity problems) adjusts given changes to both the asset and liability side. Using a numerical analysis, we show that the a higher capital ratio incentivises banks to choose an overall lower liquidity risk profile: higher capital is associated with lower probabilities of insolvency due to liquidity problems.

The model thus gives us a theoretical prediction on the link between bank capital and their liquidity risk profile. 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. This exogeneity allows us to establish causality of the impact from bank capital, with less concern for any reverse causality. By robustly measuring the empirical magnitude of the interaction, our results are useful for understanding the interaction between capital and liquidity regulation, and thereby guiding the optimal future calibration of such requirements. Understanding such interactions is a key priority for policy makers[1]. In particular, if better-capitalised banks engage in less liquidity transformation – as hypothesised in our theoretical model – relaxing liquidity and funding requirements may be warranted for a subset of banks or more broadly given the stricter capital requirements in Basel III (cf. van den Heuvel, 2016).

[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.

Using a panel analysis of 33 banks over 1989H2-2013H2, our empirical analysis supports the theoretical prediction. Banks engage in less liquidity transformation when they have more capital. We also find that to improve their liquidity risk profile, banks adjust both sides of their balance sheet. On the asset side, they increase significantly the fraction of bank assets held in the form of liquid assets. On the liability side, they increase their fraction of deposit funding and decrease their reliance on wholesale funding.

This effect seems to vary depending on the amount of excess capital buffer banks hold above the requirements. We find that banks adjust more the smaller their excess buffer – perhaps because higher excess voluntary capital buffers allow banks to react less to any increase in requirements without concern for breaching them. We also examine whether the direction of the changes in capital requirements (i.e. increases versus decreases) matters. We find that banks' behaviours are not significantly different between increase and decrease..

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 between bank capital and liquidity risk-taking. Section 4 explains the empirical approach and presents the results. Finally, section 5 concludes.

2 Related Literature

2.1 Theoretical literature

The theoretical literature on the link between bank capital and their choice of liquidity risk is still in a very early stage. The closest paper to ours is Gomez and Vo (2016) who create a model in which banks control their liquidity risk via their liquid asset positions. They find that banks choose to prudently manage their liquidity risk (i.e. hold a sufficient buffer of liquid assets) only when their leverage is low. The intuition is as follows: 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 yield less than illiquid ones. As a result, a highly leveraged bank will find it relatively expensive to insure against this risk, which incentivises the bank to take on greater liquidity risk.

Our paper is also related to the bank run literature (e.g. Diamond and Dybvig (1989) and XYZ) due to the maturity transformation that creates potentially liquidity problems. Lastly, the idea that the liability structure of a bank can have effects on its asset composition means we contribute to a large literature on the evaluation of the impact of capital regulation. While this literature is well established, see amongst others Rochet (1992), Besanko and Kanatas (1996), Blum (1999), Repullo (2004)[2], this literature has largely ignored liquidity risk. Mostly the literature to date has concentrated on the incentives capital regulation creates in respect to excessive credit risk-taking. Our paper adds to this literature by instead examining the effect of capital on incentives to manage *liquidity risk* – an area as yet largely unexplored.

2.2 Empirical literature

The empirical literature on the relationship between capital and liquidity is also fairly limited. Most prominently, Berger and Bouwman (2009) document that among US banks, more capital is associated with more liquidity creation (i.e. more liquidity transformation) for large banks, while the relationship is negative for smaller banks. Berger and Bouwman however acknowledge that this 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.[3] Hence, complementary evidence using an alternative identification strategy is of clear necessity.

De Young, Distinguin and Tarazi (2017) study the interaction between liquidity and capital among US banks using deviations from inferred firm-specific capital targets for identification. They find that when small banks fall below their capital targets they engage in less liquidity transformation. For large banks, they find no significant interaction between capital and liquidity transformation.

Distinguin, Roulet and Tarazi (2013) and Casu, di Pietro and Trujillo-Ponce (2016)

[2]For an excellent review of this literature, see Freixas and Rochet (2008), VanHoose (2007).

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

find a negative relationship between capital and liquidity creation using a simultaneous equations model for international and Eurozone banks.[4] More correlational evidence is presented by Bonner and Hilbers (2015), suggesting a negative relationship between capital and liquid asset holdings among international banks. See also Khan, Scheule and Wu (2016) who suggest that higher capital buffers mitigate the effect of funding liquidity (measured via deposits to total assets) on risk taking. [5] Finally, Sorokina et al. (2017) document that the correlation between US banks' liquidity and capital changes sign in recessions.

The above papers can only suggest correlational evidence due to the endogeneity between capital and liquidity decisions. We add to this literature by introducing exogeneity of banks' capital changes. As such, from a methodological perspective, our paper is related to several studies that use specific features 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.[6]

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 size normalized to 1. We assume that the bank is funded at date 0 by equity of amount k and retail deposits of amount $1 - k$.[7]

Investment opportunities. The bank has access to two investment opportunities. The first one is a short-term asset, referred to as liquid asset, that produces a gross deterministic return of 1 per period. The second investment opportunity is a constant

[4] Horvath, Seidler and Weill (2016) also show that capital reduces liquidity creation in a Granger-causality sense among Czech banks.

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

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

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

return to scale project, which we refer to as long-term asset. This asset requires a start-up investment at date $t = 0$ and generates a per unit cash flow $R > 1$[8] at date $t = 2$.

Withdrawal problem. Depositors can withdraw money at date 1. Denote by $\delta \in [0, 1]$ the fraction of deposits who 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. If the withdrawal amount is higher than the bank's liquid asset holdings, the latter will need to sell some (or all) of its long-term assets.

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 with the quantity of assets sold. This could be justified by the fact that the technology used by potential buyers to manage the long-term assets 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 assets. Denote by c its liquid asset holdings[9]. Hence $1 - c$ will be invested in the long-term assets.

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 link between the bank's capitalisation and its liquid asset holdings as well as its likelihood of overcoming the withdrawal problem. We will proceed backward. First, given the liquidity holdings c and the realisation of δ, we determine the unit price of long-term assets at date 1. Then, we examine the bank's optimal liquidity holdings at date 0.

[8] The assumption of deterministic cash flow of long-term assets allows us to isolate the liquidity problem from the solvency problem.

[9] Notice also that since we normalise the size to 1, c could also be interpreted as the bank's liquidity ratio.

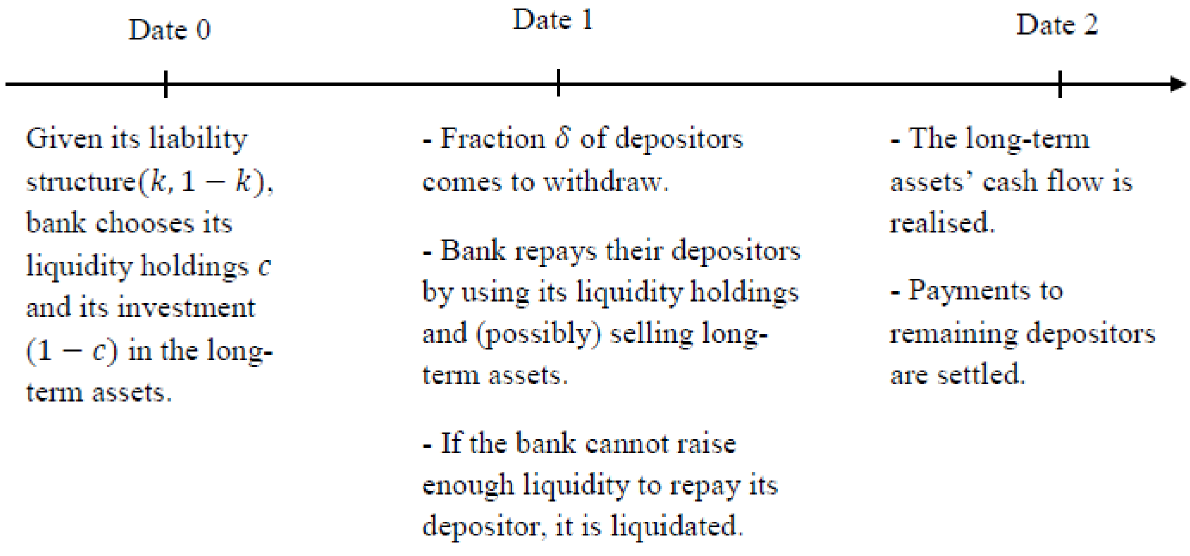


Figure 1: The timeline

3.2.1 Unit price of 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 price of this asset respectively. β and p is determined by two conditions as follows:

$$\begin{cases} \beta(1-c)p \geq \delta(1-k) - c \\ \qquad\qquad p = G\left(\beta(1-c)\right) \end{cases}$$

The inequality states that the proceeds from asset sales need to cover at least the bank's liquidity demand. The equation just 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 withdraws 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 being illiquid. Denote by $\overline{\delta}(k,c)$ the cut-off realisation value of δ above that the bank will be closed. Hence, $\overline{\delta}(k,c)$ is determined as follows:

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

$\overline{\delta}(k,c)$ is the measure of liquidity risk in our model.

3.2.2 Bank's optimal liquidity holdings

We are now equipped to analyse 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:

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

The first term is the expected profit the bank will get if its liquidity holdings are enough to cover all withdrawal, i.e. when $\delta \leq \frac{c}{1-k}$. The second term is the bank's expected profit if it could not cover all withdrawal with its liquidity holdings and has to sell a fraction of its long-term assets, i.e. when $\frac{c}{1-k} < \delta < \overline{\delta}(k,c)$. Note that 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 then equal to zero. After some algebras, we could rewrite the bank's expected profit as follows:

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

Hence, basically, the bank's expected profit is equal to the expected profit the bank would get if there is no potential liquidity problem at date 1 deducted by the expected losses it will incur if its ex-ante liquidity holdings are not sufficient to cover early withdrawals. Precisely, the second term of the RHS of Expression (4) stands for the expected losses when the bank has to sell a fraction of its long-term assets at a fire sale price (i.e. at price lower than its fundamental value). The third term corresponds to the expected losses due to the fact that the bank is closed early since it cannot raise enough liquidity even when it sells all of its long-term assets. It is easily 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 holding decision. The cost of holding liquidity is the foregone return of the long-term assets, which is represented by the term $(-c(R-1))$ in the bracket of the RHS of Expression (4). The benefit of holding liquidity lies in the reduction of the expected losses the bank has to incur.

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

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

where

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

and

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

Note that, as explained above, $A(k,c)$ and $B(k,c)$ are the two expected losses the bank has to incur if the withdrawal at date 1 is high. Therefore, the LHS of Condition (5) represents the expected marginal profit of holding liquidity to the bank. Condition (5) is then the equalisation between the expected marginal benefit and the expected marginal cost of liquidity holdings. After some arrangements, we could rewrite FOC (5) as follows:

$$\frac{\partial\overline{\delta}(k,c^*)}{\partial c}\left(k-(1-c)(1-p^e)\right)f(\overline{\delta})+\int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)}\frac{R-p^e}{p^e}f(\delta)d\delta=\int_0^{\overline{\delta}(k,c)}(R-1)f(\delta)d\delta \quad (6)$$

3.2.3 Bank capitalisation and liquidity holdings

From Condition (6), we could see that the capital ratio k affects the bank's liquidity holding through three channels, namely through the effect on the illiquidity cut-off $\overline{\delta}(k,c)$, on the equilibrium price p^e and on the threshold $\frac{c}{1-k}$. The first effect, referred to as *"skin-in-the-game effect"*, induces the bank to hold more liquidity when it has higher capital ratio. The last two effects, referred to as *"liquidity-demand effect"* instead induce the bank to hold less liquidity when its capital ratio increases.

Skin-in-the-game effect. Looking at the third term of the RHS of Expression (4), we could see that if the bank is closed at date 1, it will loose its equity. Hence, higher equity will induce the bank to reduce the probability of being closed at date 1. This is acheived by holding more liquidity since as shown in Appendix 1, higher liquidity holding will increase $\overline{\delta}(k,c)$.

Liquidity-demand effect Through the *liquidity-demand effect*, 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 the liquidity holdings are not enough to cover withdrawal. Hence, by increasing one unit of capital, the bank can reduce c while still being able to cover the same withdrawal. Second, higher capital k will increase the unit price of long-term asset p^e, which reduces the loss the bank incurs in case of selling its long-term asset. This will indeed reduce the benefit of holding liquidity and incentivise the bank to hold less liquidity.

The overall effect of bank capitalisation on its liquidity holding depends which of the above two effects is stronger.

3.2.4 Bank capitalisation and liquidity risk

The impact of banks' capitalisation on their liquidity holdings is not the whole story yet. As explained above, due to *liquidity demand effect*, banks may decrease their liquidity holdings when they have higher capital ratio. This decrease in liquidity holdings does not necessarily mean an increase in banks' liquidity risk profile. In this model, the impact of banks' capital ratio on the level of banks' liquidity risk is reflected in the impact of k on the illiquidity threshold $\overline{\delta}$ that determines the probability banks fail following big withdrawal. From Equation (2), using implicit differentiation rule, we get

$$\frac{\partial\overline{\delta}}{\partial k} = \frac{\delta + (1-c)\frac{\partial p^e}{\partial k} + (1-p^e)\frac{\partial c}{\partial k}}{1-k} \tag{7}$$

Hence, banks' capital ratio has three effects on banks' liquidity risk. The first effect, represented by the term δ in the numerator of Expression (7) reflect the impact of stable liability structure on the liquidity risk. Clearly, the higher the banks' capital ratio is, the more stable the banks' liability structure, which reduces the expected outflow and thus, reduce the liquidity risk for any given level of liquidity holdings. The second effect work through the impact on the price of long-term asset: since higher capital ratio reduces the expected outflow, it will reduce the amount of long-term asset banks would need to sell, which increase the price. The final impact is the impact of banks' capital ratio on banks' liquidity holdings.

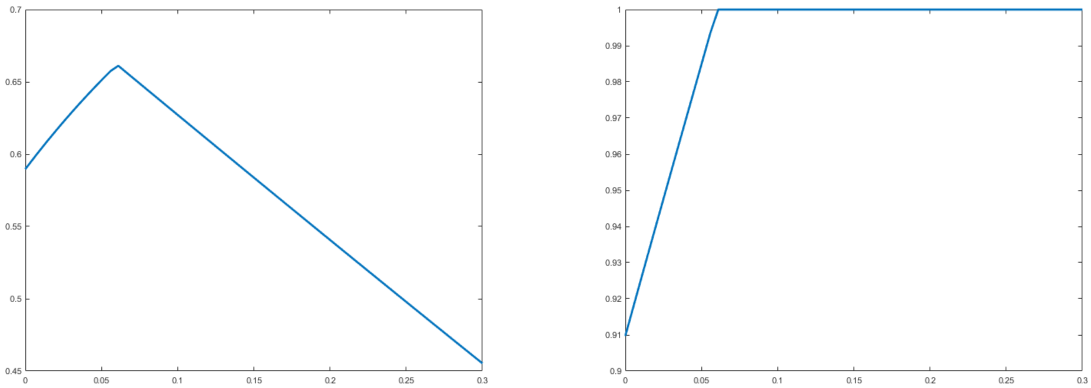
From Expression (7), we see that if higher capital ratio induces more liquidity holdings, it will increase the illiquidity threshold and thus reduce liquidity risk. If higher capital ratio induces banks to hold less liquidity, then the overall effect on the liquidity risk will depend on whether the negative impact via liquidity holdings is stronger than the two positive effects via 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 shows respectively the bank's optimal liquidity holdings and its probability of surviving at date 1 as a function of its capital ratio when $R = 1.1$.



(a) Optimal liquid asset holdings as function of k

(b) Bank's survival probability as function of k

Hence, in this numerical example, higher capital ratio induces the bank to choose less liquidity risk since its probability of surviving the liquidity shock is increasing with k.[10] Regarding the link between banks' capital ratio and liquidity holdings, we could see that when k is low enough, the *skin-in-the-game effect* is stronger since the probability of failing is high and a small increase in k would have big impact on this probability. When k is high enough, the failing probability is low and increase in k will not help to improve it much. In that situation, the banks' optimal liquidity holdings is decreasing with the banks' capital ratio since liquidity demand decreases.

4 Empirical strategy and results

4.1 Background on UK regulatory regime

We exploit data from the period during which the first version of the Basel Accord was in effect in the UK. This regulatory regime, dubbed Basel I, was relative simple: bank capital was required to be at least 8% of risk-weighted assets (RWAs) where risk-weights corresponded to coarse time-invariant categories. The key feature, specific to the UK, is that the supervisor could impose a requirement in excess of the 8% minimum:

[10] This result is robust to different choices of numerical values for R and to different choices of distribution for δ and technology $G(.)$.

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 could also change them over time. Moreover, these requirements were set separately for the banking book and the trading book and banks had to comply with both.

Of particular importance to our study, 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". See also Aiyar et al. (2014) whose empirical analysis shows 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, at semi-annual frequency. It covers a period from 1989H2 to 2013H2 and is unbalanced, given that some firms go bankrupt, other are bought and new entrants join the market (either new banks created or foreign banks opening a subsidiary in the UK). The dataset has information on actual and required levels of capital as well as measures of bank balance sheet characteristics.[11]

Our sample. To construct our sample, we apply the following filtering criteria to the above dataset. First, since the original dataset is built from a collation of different reporting template of various quality, to improve the credibility of the reported data, we include in our sample only the largest 25 banks that operate in the UK at a consolidated level.[12] Then, to make sure that changes in banks' capital are the result of the changes

[11] We treat mergers as a continuity with the dominating bank of the merger. For example, the result of the merger between RBS and Natwest in 2000 is treated as continuity of RBS.

[12] We rank banks based on their total assets for each semester. To have a stable sample we only

in requirements imposed by supervisors, we track every single change in the requirement that are greater than or equal to 5bp of the banks' total risk-weighted assets as Bahaj and Malherbe (2016). Finally, we also remov all unreasonable data points such as capital ratio to RWA greater than 100%, liquid assets over total assets lower than 0% or greater than 100% for example. Applying those filters leaves us with an unbalanced panel of 906 observations for 33 banks. Table 1 shows summary statistics for the banks in our sample.

Table 1: Summary statistics

	observations	mean	standard deviation	min	max
Individual capital guidance (to RWA)	906	0.101	0.0247	0.0800	0.458
Actual regulatory capital ratio (to RWA)	906	0.153	0.0716	0.0542	0.598
Excess capital buffer (to RWA) above the requirements	906	0.0513	0.0635	-0.0422	0.482
Return on assets	906	0.00176	0.00944	-0.0966	0.0650
Non performing loans over total loans	906	0.0537	0.135	0	0.947
Net impairments over total loans	876	0.00791	0.0128	-0.0892	0.152
Total assets (in million £)	906	161,353	328,090	294.8	$1.832*10^6$
Changes in Individual capital guidance (to RWA)	242	0.00117	0.0318	-0.234	0.378

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 FSA in 1997 (Bahaj and Malherbe, 2016, De-Ramon et al., 2017). During and after the financial crisis, ICG has been used more frequently and more broadly, signaling a more pro-active

include banks that are in the top 25 banks for more than 40% of their existence. Our main results hold for alternative definition of this threshold. Our main results also hold for alternative threshold for the largest banks.

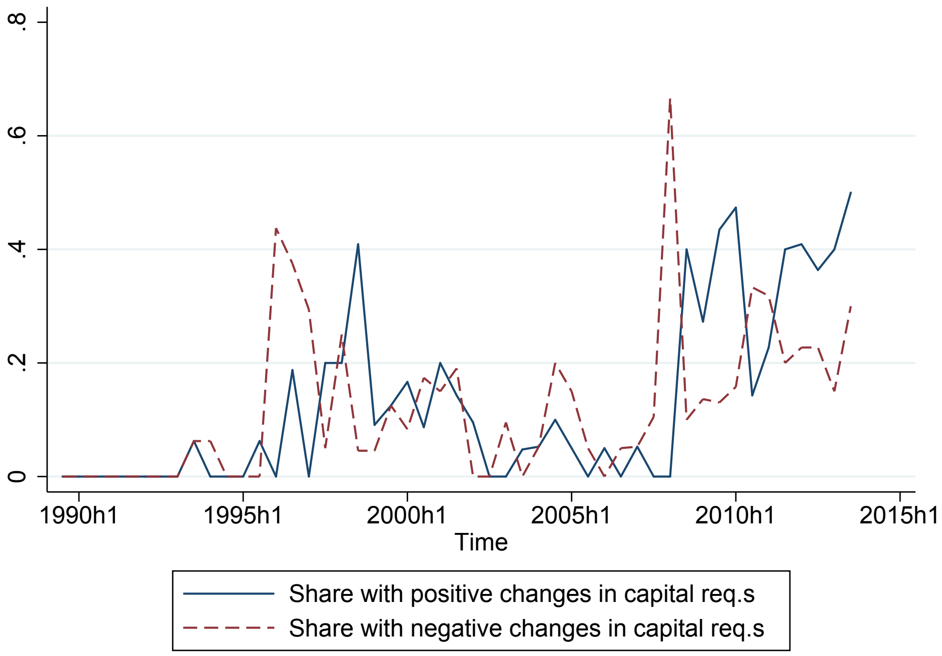


Figure 3: Bank-level capital requirement changes over time

supervisor.

4.2.2 Measure of banks' capital

To exploit the exogeneity of changes in banks' capital requirements imposed by the supervisor, 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. Note that binding capital requirements should not be confused with banks always holding capital at the level of the minimum regulatory requirement. Rather, binding capital requirement merely implies that banks must 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 complying with 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

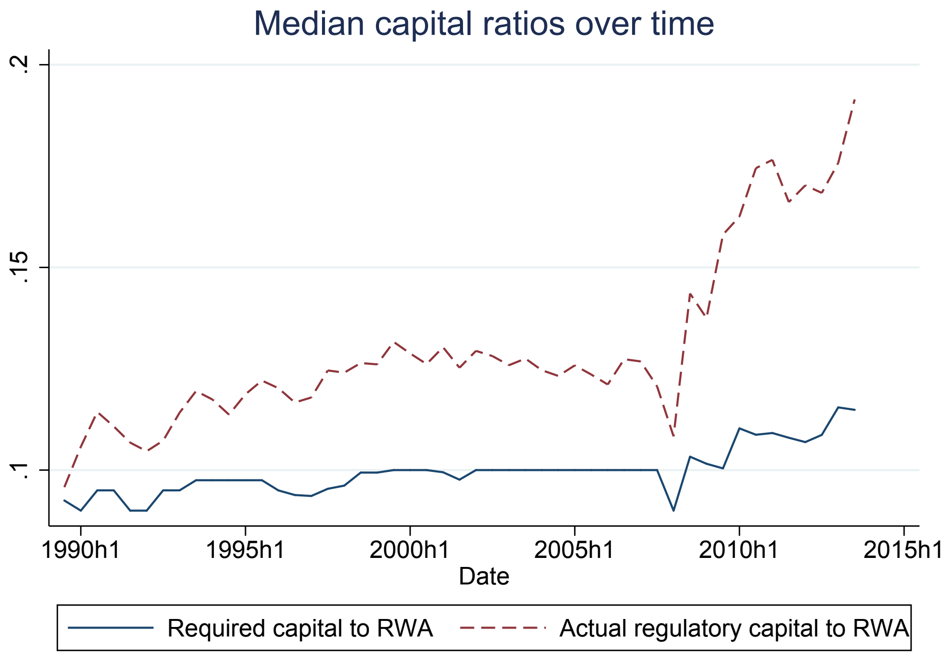


Figure 4: Evolution in actual and required capital ratios

the banks' capital ratio choices. 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 confirms previous conclusions of Alfon et al (2005), Francis and Osborne (2009), and Bridges et al. (2013) 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 Measures of liquidity risk

Our main liquidity measure is based on the liquidity creation measure used by Berger and Bouwman (2009), henceforth referred to as the BB liquidity index. We diverge slightly given that we scale the measure to make it comparable between banks. In addition, we 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.[13]

Our main measure is:

$$liq.creation = \frac{\sum_i notionalvalue_i \times weight_i}{assets + offBScommitments\&guarantees}$$

where the weights are determined by the classification scheme on table 2. The higher the measure, the more the bank engages into liquidity transformation.

The liquidity index based on Berger and Bouwman (2009) is based on the ease, cost and time for banks to meet creditors' demand (liability side), and the ease, cost and time to obtain liquid funds (asset side). 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; it is nearly impossible for a shareholder to ask the bank to buy back its shares, and retained earnings belong directly to the bank. Loans are considered illiquid since they are difficult to sell on a secondary market, while gilts are liquid assets as there is a large and liquid secondary market.

Maximum liquidity is created when illiquid assets are funded by liquid liabilities. For example, suppose £1000 of loans (an illiquid asset) is funded by £1000 of deposits (a liquid liability).[14] This creates £1000 of liquidity,[15] which equals 1 on the liquidity index because we scale by total assets. On the other hand, maximum liquidity is destroyed when liquid assets are funded by illiquid liabilities. For instance, £1000 of Gilts (weight of -0.5) are funded by £1000 of equity (weight -0.5). This gives £-1000 of liquidity,[16] or -1 on the liquidity index since it is scaled by total assets. In this case the bank has taken no liquidity risk. 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 of: $-0.5 * 100 + 0.5 * 900 + (-0.5) * 100 + 0.5 * 900 = 800$. And after scaling by total assets: $800/1000 = 0.8$.

[13] 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. Table **??** in the appendix shows that our main results hold.

[14] This can also be seen as maximum liquid risk-taking since depositors can request funds at any point, but the loan is illiquid.

[15] Since $0.5 * 1000 + 0.5 * 1000 = 1000$ and, in the example, both are weighted by 0.5.

[16] Since $-0.5 * 1000 + (-0.5) * 1000 = -1000$

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: 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

This index is a liquidity transformation measure. As alluded to above, you can also see it as measure of liquidity risk. Liquidity transformation is positively correlated with liquidity risk: a higher mismatch between assets and liabilities generates higher potential losses.

In our baseline measure, we consider deposits to be a liquid liability (as in Berger and Bouwman, 2009), hence exposed to runs. The recent crisis and the run on Northern Rock in 2007 has shown us that this characteristic of deposits is still of relevance (despite deposit insurance). Nevertheless, deposits are usually rather sticky and stable. As a result, we also build an alternative measure to test this, where we consider deposits to be a illiquid liability and show that it actually reinforces our main result.

In table 3 we see that the components of the BB liquidity index vary among the banks in our sample and reflect the variety of banks in our dataset. Some banks have no liquid assets, while some have no customers deposits (they are pure investment banks).

Table 3: Summary statistics (over gross total assets, GTA)

	observations	mean	standard deviation	min	max
Liquid assets	906	0.162	0.134	0	0.947
Semi-liquid assets	906	0.430	0.205	0	0.995
Illiquid assets	906	0.235	0.155	0	0.798
Customers deposits	906	0.434	0.179	0.000292	0.851
Wholesale funding	906	0.327	0.188	0.0207	0.965
Off-balance sheet guaranties	906	0.174	0.117	-0.0385	0.552

Notes: Gross total assets include derivatives and off-balance sheet commitments.

We also build a liquidity measure based on the NSFR following BCBS (2014). This measure is a ratio of available stable funding over required stable funding that measures the maturity mismatch of banks. Conceptually, it is close to the measure of Berger and Bouwman (2009) given that it compares stable funding (or illiquid liabilities) to illiquid assets (see Table 4), but an important difference lies in the treatment of deposits, which are considered as liquid in Berger and Bouwman (2009), while they are considered as a stable source of funding in the NSFR.

The NSFR index is calculated as follows:

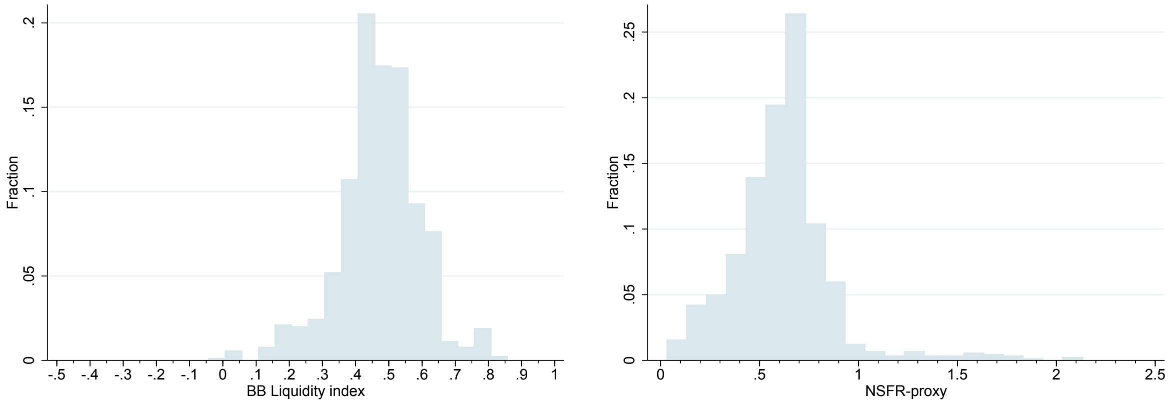
$$NSFR = \frac{\sum_i availablefunding_i \times weight_i}{\sum_j requiredfunding_j \times weight_j}$$

Contrary to the liquidity index based on Berger and Bouwman (2009), the higher the NSFR, the more banks take liquidity risk.

Table 4: NSFR index

Available stable funding		**Required stable funding**	
Liabilities	weight	Assets	weight
Capital	1	Other assets	1
Customers deposits	1	Mortgages and other loans	0.85
Other liabilities	0	Trading book	0.5
		Other commitments	0.05
		Liquid assets	0

Figure 5: Distribution of our liquidity measures



(a) Distribution of the BB liquidity index (b) Distribution of the NSFR-proxy

4.3 Econometric methodology

4.3.1 Specification

Using bank-level data, our main regression is:

$$LiqMeasure_{i,t} = \beta_1 + \beta_2\ CapReqMeasure_{i,t} + \beta_3\ controls_{i,t-1} + u_i + time_t + \epsilon_{i,t} \quad (8)$$

where i represents a bank and t the time-period. $LiqMeasure$ is one of our measures of liquidity risk and $CapReqMeasure$ is our measure of capital requirements expressed as a required percentage of capital over total regulatory RWAs. We add a set of bank level variables ($controls$) to control for banks' risk profile: return on assets, non-performing loans over total loans and impairments over total loans;[17] and the liquidity regime they are subjected to as explained below. Controls are lagged by one period to reduce potential endogeneity problems. We estimate this model using fixed effects at the bank level (u) to account for average differences over time across banks that are not captured by other exogenous variables and to reduce correlation across error terms, and time fixed effects ($time$) to control for average differences in our liquidity measure across years. All regressions are estimated using robust standard errors, clustered by bank.. Finally, ϵ is

[17] The three variables are not strongly correlated, thus the inclusion of the three should not create any problems.

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 single one, covering all banks (with some exemptions, see Banerjee and Mio, 2017): the Individual Liquid Guidance. We 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, banks' capital and banks' liquidity are to some extent jointly determined. To mitigate this potential endogeneity problem and establish causality, we exploit a specific feature of UK regulatory regime as described in Section 4.1. Of course, changes in a bank's individual capital requirements were not literally random. However, the key condition for a causal interpretation to be valid in our analysis is that changes in capital requirements imposed by regulators are not driven by changes in banks' liquidity risk. There are indeed many reasons to believe that liquidity risk was 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 FSA, the previous U.K. regulator, involved more focus on organisation structures, systems and reporting procedures than on overall risks in business models. The underlying reason for this focus is the philosophy that the primary responsibility for managing risks lies with the senior management and boards of individual firms who are better placed to assess business model risk than bank regulators. The latter would thus focus on making sure that appropriate systems, procedures and skilled people are in place. Bahaj and Malherbe (2017) were able to track some of the confidential letters sent by the supervisor to the banks to notify 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 FSA to liquidity risk in firms. For example, Paragraph 164 of the FSA Board Report on the failure of the Royal Bank of Scotland wrote:

'The Supervision Team commented to the Review Team that analysis of liquidity returns was not a focus of its supervision during the Review Period[18] *due, in part, to the limitations of SLR. 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 lessons learned, the FSA made reforms to increase the attention given to liquidity risk. However, liquidity risk is taken into account by changes in liquidity requirements instead of capital requirements.[19] Paragraph 200 of the same report highlights that in response to the Turner Review's recommendation on fundamental reforms to the regulation and supervision of liquidity, "*the FSA has introduced a radically changed liquidity regime, enforced via a more intensive supervisory framework for liquidity*".

4.4 Empirical results

4.4.1 Bank capital and liquidity risk

Our main results on the link between banks' capitalisation and their liquidity risk are presented in the first two columns of Table 5. For both of our liquidity risk measures, we find that higher capital ratios induce banks to reduce their liquidity risk profile. This is in line with our theoretical findings.

We also run alternative specifications for robustness as shown in the last three columns of Table 5. Our main result holds with alternative versions of the liquidity index. In column three, we consider deposits as stable (ie. an illiquid liability with a coefficient of

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

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

Table 5: Main results

VARIABLES	(1) BB liquidity index	(2) NSFR	(3) BB liquidity index (deposits)	(4) BB liquidity index	(5) BB liquidity index
Capital req.	-0.273***	1.496***	-0.759***		-0.933***
	(0.0856)	(0.225)	(0.248)		(0.211)
Capital req. (lagged)				-0.217***	
				(0.0785)	
Constant					0.581***
					(0.0912)
Observations	816	816	816	764	820
R-squared	0.860	0.714	0.816	0.865	0.381
Controls	YES	YES	YES	YES	YES
Methodology	FE	FE	FE	FE	OLS
Adj. R2	0.843	0.680	0.794	0.848	0.375
Adj. R2 within	0.0439	0.228	0.159	0.0404	
Banks	33	33	33	32	37

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

-0.5). In the fourth column, we show that a change in ICG has lasting effect with the coefficient on the lagged variable that is significant. Finally, in the last column, we find similar results with a higher coefficient using pooled OLS.

4.4.2 Banks' balance sheet adjustments

Our main result suggests that an increase in bank capital induces banks to reduce their liquidity risk. To understand what adjustments banks made to achieve this liquidity risk profile, we examine in Table 6 the relationship between banks' capital requirements and different components of their balance sheet. To do so, we adapt our main regression 8 and replace the dependent variables by the six unweighted components of the BB liquidity index: liquid assets, semi-liquid assets, illiquid assets, deposits, wholesale funding and off-balance sheet. The variables are measured as ratios over total assets.

The first observation is that banks adjust both sides of their balance sheet. On the asset side, the share of bank assets held in the form of liquid assets increases, while semi-liquid assets have a negative coefficient and the coefficient on illiquid assets is insignificant. This suggests following an increase in capital requirement, banks adjust their liquidity risk by rebalancing their portfolio towards more liquid assets (e.g. gilts).

On the liability side, we find significant coefficients to suggest that following an increase in capital requirements, banks increase their share of deposit funding, and decrease their share of wholesale funding, which overall contributes to reduce their liquidity risk.

4.4.3 Driving channels

To explore the drivers of the relationship between bank capital and liquidity risk, we further decompose the coefficient β_2 using a relevant variable Z:

$$\beta_2 = \beta_3 + \beta_4 \; Z_{i,t} \tag{9}$$

We estimate the following equation:

Table 6: Banks adjustments (non-weighted ratios over total assets)

VARIABLES	(1) liquid assets	(2) semi-liquid assets	(3) illiquid assets	(4) deposits	(5) wholesale funding	(6) off-balance sheet
Capital req.	0.923***	-0.989***	0.0833	0.486*	-0.467**	0.127*
	(0.193)	(0.321)	(0.182)	(0.248)	(0.185)	(0.0734)
Observations	816	816	816	816	816	816
R-squared	0.693	0.811	0.906	0.773	0.811	0.774
Controls	YES	YES	YES	YES	YES	YES
Adj. R2	0.656	0.789	0.895	0.746	0.789	0.748
Adj. R2 within	0.111	0.0873	0.0948	0.171	0.299	0.0842
Banks	33	33	33	33	33	33

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

$$LiqMeasure_{i,t} = \beta_1 + (\beta_3 + \beta_4\ Z_{i,t}) *\ CapReqMeasure_{i,t} + \beta_5\ Z_{i,t} + \beta_6\ controls_{i,t-1} + u_i + time_t + \epsilon_{i,t}, \tag{10}$$

This equation investigates if the effect of capital on banks' choice of liquidity risk varies across the variable Z. We focus on two variables: the excess voluntary capital buffer banks hold above their requirements, and the direction of the changes in capital requirements (i.e. increases versus decreases). To examine the impact of the excess voluntary capital buffer, the interaction variable Z is included in Equation (10) as a continuous variable. For the potential difference between the impacts of an increase and a decrease, Z is treated as a dummy: it is equal to 1 for an increase and zero otherwise.[20]

Excess capital buffer With respect to the role of the excess capital buffer, Figure A.2 in the appendix represents the distribution of the excess voluntary capital buffer banks hold in our sample. Overall, 90% of banks in our sample have buffers lower than 25% of RWAs and only very few banks have voluntary buffers larger than 50%.

Table 7 presents our findings on the role of excess voluntary capital buffers. A positive

[20]We do not introduce the stand-alone variable $Z_{i,t}$ given that it does not carry any economic meaning.

coefficient for the interaction term means that the higher the excess voluntary capital buffer is, the lower the extent to which banks reduce their liquidity risk profile when capital requirements increase. We plot in Figure 6 the total coefficient as a function of the level of the voluntary buffer following Equation 9 . The total effect of a change in capital requirements is only significant for voluntary capital buffers below 25% of RWAs, which, as mentioned above, represents around 90% of our sample.

Table 7: Capital buffer

VARIABLES	BB liquidity index
Capital req.	-1.029***
	(0.115)
Capital buffer	-1.061***
	(0.126)
Capital req. * buffer	4.295***
	(1.402)
Observations	816
R-squared	0.888
Controls	YES
Methodology	FE
Adj. R2	0.874
Adj. R2 within	0.235
Banks	33

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

This result, together with the fact that the independent variables are contemporaneous, is consistent with the view that higher excess voluntary capital buffers allow banks to react less to any increase in requirements – without concern for breaching them. In the academic literature on bank capital buffers, the voluntary buffer is also considered to reflect a bank's risk appetite: the higher the excess voluntary buffer banks hold above requirements, the more risk-averse they are. However, since our independent variables are contemporaneous, we cannot test this theory.

Increase vs. decrease. Our sample includes both increases and decreases in banks' capital requirements. As shown in Figure 3, the number of capital increases and capital decreases are rather similar, which allow us to analyse the differential effect. Figure A.1

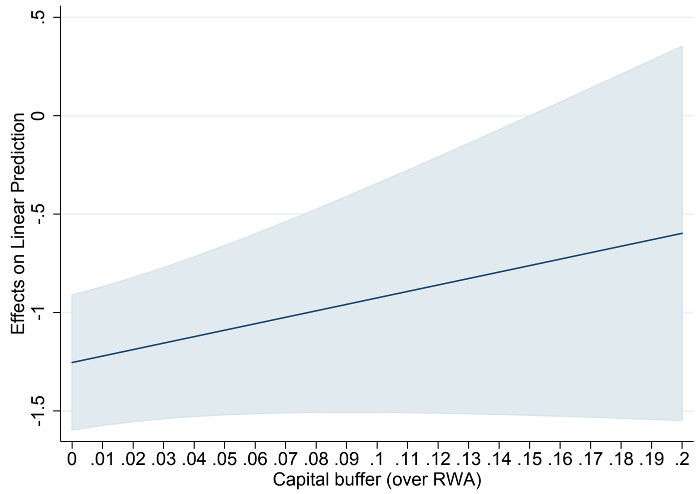


Figure 6: Effect of capital requirements with relation to capital buffer size

in the appendix provides the distribution for the size of the change. This distribution is rather symmetrical, both increases and decreases are mostly small changes (in 60% of cases, new capital guidance implies a less than 1% change, and there are very few cases of changes in the ICG greater than 4%.). The absence of large changes in the ICG is comfort for our finding that banks adapt rather quickly to the new requirement, they do not have to carry a complete revamp of their balance sheet after each review.

Table 8 presents our results on the differential effect between an increase and a decrease in capital requirements. We see that the coefficient for the interaction term is positive but insignificant. Hence, banks' behaviours are not significantly different between increase and decrease.

5 Conclusions

We have shown in a simple theoretical model with retail deposit withdrawals and fire-sales that firms take less liquidity risk with higher capital. We confirm this relationship in a robust empirical assessment. Our results indicate that banks engage in less liquidity transformation when they are better capitalised. We also find that banks adjust more the smaller their excess buffer – perhaps because higher excess voluntary capital buffers allow banks to react less to any increase in requirements without concern for breaching them. Lastly, we find that to adjust their liquidity risk after a change in capital requirements,

Table 8: Increases versus decreases of capital requirements (total effect)

VARIABLES	BB liquidity index
Capital req.	-0.279***
	(0.0794)
Capital req. * $I_{increase}$	0.00696
	(0.0504)
Observations	816
R-squared	0.860
Controls	YES
Methodology	FE
Adj. R2	0.843
Adj. R2 within	0.0426
Banks	33

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

Notes: The coefficients of this table are the total effect, following the equation 9. The table with the products between capital requirements and the dummies is in the appendix (Appendix **??**).

banks will mainly adjust their liquid asset holdings and reliance on wholesale funding. The results suggest that capital and liquidity requirements are at least to some extent substitutes. Moreover, our results should be of help in the calibration of macroprudential requirements by informing how banks might change their level of liquidity risk after a change (either an increase or decrease) in macroprudential buffers.

A Appendix

A.1 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%.

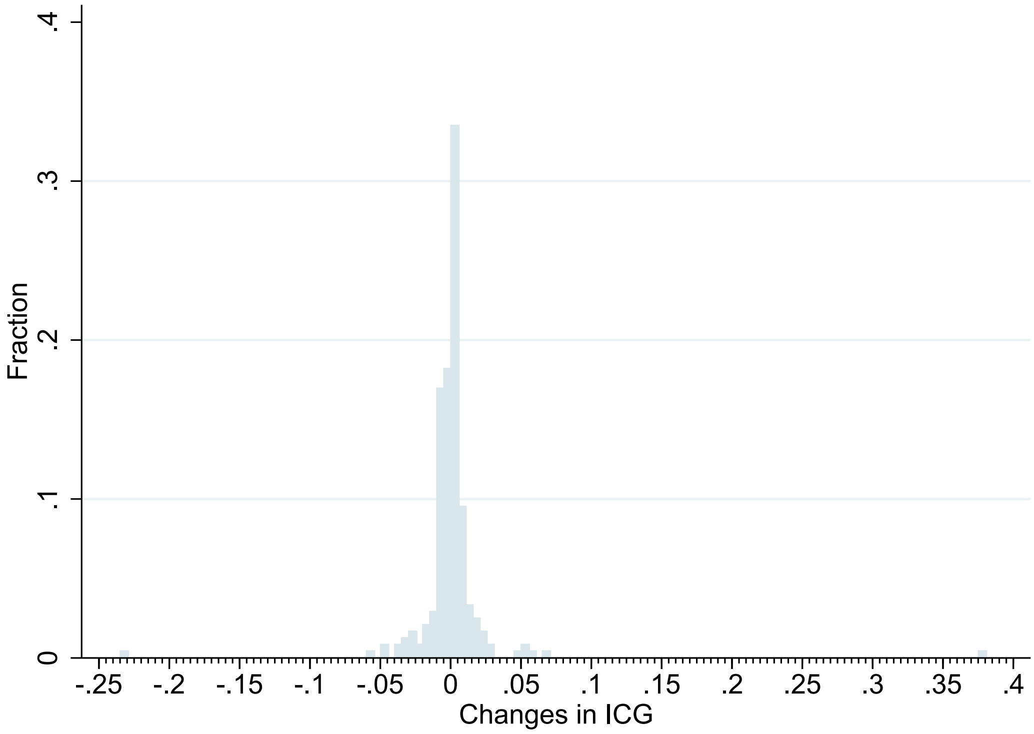


Figure 7: Distribution of changes in capital requirements

A.2 Distribution of capital buffers

This histogram represents the distribution of the excess capital buffer banks hold in our sample. Overall, 80% of the banks in our sample have buffers lower than 20% of RWA and only very few banks have buffers larger than 50%.

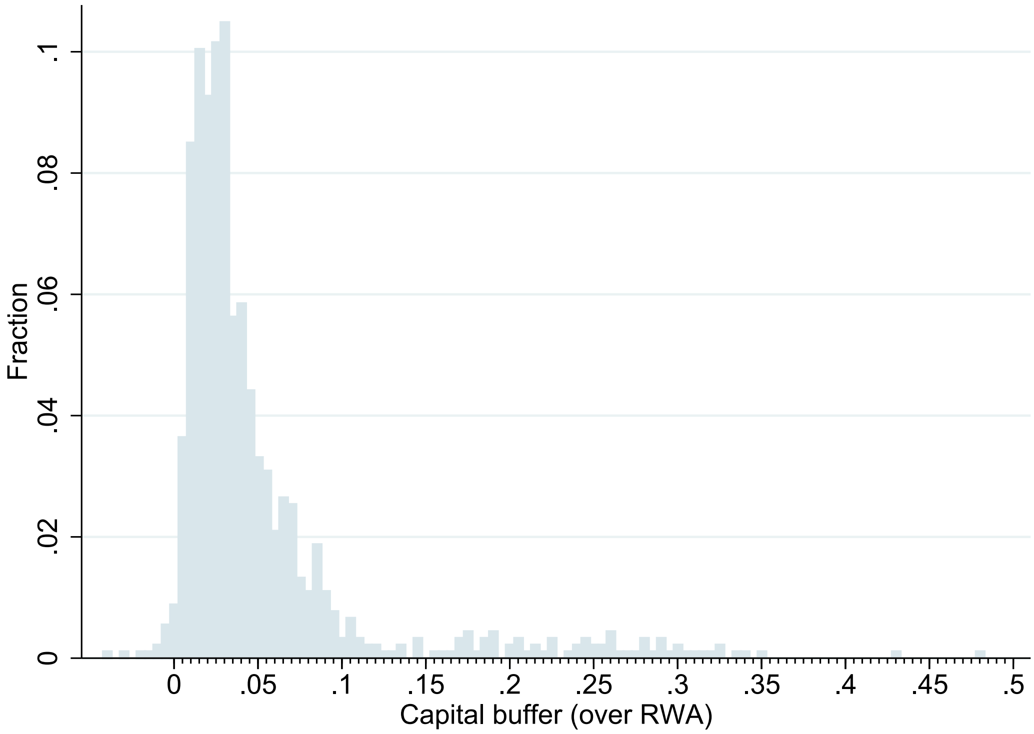


Figure 8: Distribution of capital buffers

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.

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