BANK OF ENGLAND

Staff Working Paper No. 840

Capital and liquidity interaction in banking

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June 2020

This is an updated version of the Staff Working Paper originally published on 20 December 2019

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Capital and liquidity interaction in banking

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Abstract

We study how banks' capital level affects the extent to which they engage in liquidity transformation. We first construct a simple model to develop testable hypotheses on this link. Then we test our predictions and establish the causality using a confidential Bank of England dataset that includes arguably exogenous changes in banks' capital requirement add-ons. We find that banks engage in less liquidity transformation when their capital increases, which suggests that capital and liquidity requirements are at least to some extent substitutes. We also find that this substitution is mostly driven by small banks. These results have interesting implications for the optimal joint calibration of capital and liquidity requirements and for the proportionality of prudential regulations.

Key words: Banking, liquidity transformation, capital requirements and financial regulation.

JEL classification: G21, G28, G32.

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We are grateful for helpful comments from Kartik Anand (discussant), Thorsten Beck, Stephen Cecchetti, Bill Francis, Iftekhar Hasan, Renata Herrerias (discussant), Antoine Lallour, Tobias Neumann, Lev Ratnovski (discussant), Vicky Saporta, Noam Tanner (discussant), Amine Tarazi, Alejandro Van der Ghote (discussant), Matthew Willison and participants at the 2020 Federal Reserve System Day-Ahead Conference in San Diego, US; the European System of Central Banks' (ESCB) Day-Ahead Conference 2019 in Lisbon, Portugal; EEA 2019 in Manchester, UK; 2019 BCBS RTF – CEPR join Workshop in Basel, Switzerland; EFMA 2019 in Azores, Portugal; IBEFA-WEAI 2019 conference in San Francisco, US; Global FMA 2019 conference in Bogota, Colombia; FEBS 2019 annual conference in Prague, Czech Republic; RES 2019 annual conference in Warwick, UK; INFINITI 2018 conference in Poznan, Poland; and IFABS 2018 conference in Porto, Portugal; the 2017 Workshop for Future Bank Regulation in Limoges, France; EBA 2017 policy research workshop in London, UK. We also thank Sebastian de-Ramon for invaluable data guidance and helpful comments. Casey Murphy and Philip Massoud provided valuable research assistance. The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England. Milonas' contribution to this paper was mainly carried out when he was employed by the Bank of England. The views expressed herein are solely those of the author and do not represent the views of his employer, Moody's Analytics, its parent company (Moody's Corporation) or its affiliates.

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ISSN 1749-9135 (on-line)

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 requirements. Whereas the goal of capital regulations is to improve bank solvency, liquidity requirements aim to prevent banks from aggressively engaging in liquidity transformation, which can expose them to excessive liquidity risk in a downturn. The introduction of the latter alongside the former, which has existed for a long time, naturally raises questions on how the two regulations interact and how they could be jointly designed. Policy makers therefore could benefit from understanding the interaction between banks' capital and their liquidity decisions.

In this paper, we aim to shed light on these questions by examining how a bank's capital level affects its incentives to engage in liquidity transformation. Answering this question helps to understand whether actions leading to changes in bank capital can produce similar effects on the resilience of a bank's liquidity risk profile as changes in liquidity requirements can. This in turn has interesting implications for the joint design of the two regulations since it allows us to assess whether tightening capital requirements increases or decreases the returns on tightening liquidity requirements.

We tackle the question by building both theoretical and empirical evidence. Our simple theoretical banking model clarifies potential channels for the impact of bank capital on bank liquidity and helps develop hypotheses. These predictions are then taken to the data. In our theoretical setting, banks are featured as intermediaries that provide liquidity to their customers, which in turn exposes them to funding liquidity risk. Banks manage this risk by maintaining a stock of liquid assets. The model focuses on analysing how banks' capital level affects banks' incentives to hold this stock and, through that, banks' overall vulnerability to liquidity risk. It therefore produces two theoretical predictions about the effects of banks' capital on their asset liquidity and on their overall degree of liquidity transformation. Our empirical assessment tests these predictions by exploiting arguably exogenous changes in capital requirements imposed by UK supervisors on banks in UK.

Our contribution is twofold. First, the two-pronged approach provides a solid theoretical underpinning for our empirical tests and their interpretation. Our theoretical setup, although simple, captures a key source of banks' exposure to liquidity risk, namely liquidity provision. It clarifies two main channels through which the banks' capital ratio could affect the liquidity of their assets. First, a higher capital ratio means that banks have a more stable liability structure, which in turn implies a lower need for liquidity holdings and so induces banks to hold less liquid assets - *"liquidity-demand"* effect. Second, a higher capital ratio leads to a higher cost of early liquidation due to insufficient liquidity holdings - *"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. In terms of how a bank's capital impacts its overall liquidity transformation, this impact depends on the relative strength of the effects on its asset liquidity and its liability structures. Using a numerical analysis, we find that the relationship between bank capital and asset liquidity is of an inverted U-shape, while with respect to liquidity transformation, a higher capital ratio will monotonically lead to a lower degree of liquidity transformation.

Our second contribution lies in our strategy to establish causation in the link between bank capital and bank liquidity. Since in practice, both may be jointly determined, endogeneity is one of the main challenges for our empirical analysis of the relationship between them. In a fairly limited literature on this relationship, some papers have resorted to mainly making correlational claims instead of causal ones, while others have attempted to use simultaneous equations models or deviations from inferred bank-specific capital targets to deal with the endogeneity (e.g. Distinguin et al. (2013). Our identification strategy instead uses bank-level regulatory capital add-ons imposed by UK supervisors to banks in the UK. Changes in these add-ons can be claimed to be exogenous to a bank's liquidity profile. The reason for such exogeneity is that when setting those add-ons, as highlighted in Turner Review (2009), UK supervisors focus on organisational structures, systems and reporting procedures rather than financial risks of banks.

Our empirical methodology is thus to regress measures of bank liquidity on banks' required capital ratios. To measure banks' asset liquidity, we use the simple ratio of liquidity holdings over total assets. To proxy for the extent to which banks engage in liquidity transformation, our analysis uses a measure developed by Berger and Bouwman (2009). 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 of liquidity mismatch between the 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, the Berger and Bouwman measure constitutes a natural proxy for a bank's degree of liquidity transformation.

The sample we use to test our predictions is a panel of 154 banks over 1989H2-2013H2. We find that the data empirically supports the inverted U-shape relationship between between bank capital and liquidity holdings. 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. Changes in banks' capital appear to have a long lasting effect on banks' liquidity transformation with the existence of a significant impact up to 1.5 years later. When examining how banks adjust to reduce their liquidity mismatch, we find that banks predominately react through the asset side of their balance sheet by increasing significantly the fraction of bank assets held in the form of liquid assets.

To exploit additional heterogeneity of our dataset on time variation and banks' size, in the empirical analysis, we go beyond the theory and explore whether the impact of banks' capital on their liquidity transformation differs across banks with different sizes and across pre- and post-crisis periods. We do not find a significant change in the relationship between capital and liquidity after the crisis in 2007, which suggests that the 2007-08 financial crisis does not seem to have been a structural changer for this relationship. In relation to banks' size, we do find a significant difference in the behaviour of small vs. the largest banks, which is analogous to the findings of Berger and Bouwman (2009). Interestingly, we find that the effect of size on the interaction between bank capital and bank liquidity is not continuous with respect to size, but size seems to matter only above a certain threshold.

Our paper contributes to an early but growing literature on the interaction between capital and liquidity in banking. On the theoretical side, contributions include, among others, Vives (2014), Koenig (2015), Gomez and Vo (2019) and Carletti et al (2020). While Gomez and Vo (2019) focus on the impact of the leverage distribution in the banking system on the fire-sale problem, Vives (2014), Koenig (2015) and Carletti et al (2020) use the global games framework to study the interaction between bank capital and bank liquidity via their impact on the probability of runs. Our theoretical framework is designed to lay out, in a transparent way, important channels for the link between bank capital and the choice of liquidity transformation, which in turn helps developing hypotheses for our empirical tests.

On the empirical side, 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.[1] 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.[2] Finally, Sorokina et al. (2017) document that the correlation between US banks' liquidity and capital position 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.[3]

DeYoung et al. (2018) also study the interaction between liquidity and capital among

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

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

[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 difficult since the share of seniors might also affect banks' investment opportunities, which in turn may affect their liquidity creation choices.

US banks. Their identification strategy relies on a negative shock to bank capital such that the capital ratios of banks that already operate below their own internal capital target go further below that target. Since this reduction would be involuntary for banks, the shock could constitute an exogenous change to bank capital. 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.[4]

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

2 Theory

This section presents a simple model of bank liquidity management. It lays out important channels on the link between a bank's capital and its choice of liquidity transformation, which in turn helps develop hypotheses for our empirical tests. The model is designed to capture in a minimalist fashion the two main characteristics of banks. First, a bank's role is to provide liquidity to customers. Therefore, they are, at least partly, funded by debts that could be withdrawn on demand and, as consequence, exposed to funding liquidity risk. Second, given their exposure to this risk and given that it is costly for banks to raise external finance unexpectedly, banks maintain a stock of liquid assets

[4] 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).

to meet withdrawal demands and manage their vulnerability to liquidity shocks.

2.1 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. The bank's assets and liabilities are described sequentially below.

Assets The bank could invest in two types of assets. The first one is long-term assets that require a start-up investment at date $t = 0$ and generate cash flows after two periods, i.e. at $t = 2$. To completely isolate the liquidity problem from the problem of credit risk, we assume that long-term assets are safe. Precisely, we assume that they produce at $t = 2$ a deterministic cash flow of $R > 1$ per unit of investment made at $t = 0$. The other type of assets are referred to as liquid assets. They differ from the long-term assets in two main aspects as follows.

First, they are less profitable since they produce a gross deterministic return of 1 per period. The assumption that the gross return of liquid assets is equal to one is made for simplicity. All our results will hold if we assume a gross return of r as long as $r^2 < R$.

Second, as the name indicates, liquid assets are easier to be converted into cash than long-term assets. In particular, we assume that liquid assets can be monetised one by one while long-term assets can only be sold with significant impact on their value. We justify significant price discount by the fact that long-term assets are specific. This specificity implies that investors outside the banking sector are less able than banks in managing those assets, which in turn implies that the price the former is willing to pay for those assets is lower than the cash flows the bank can generate. To capture the idea of fire sales due to asset specificity, we introduce a function $G(q)$ representing the cash flows that outside investors would produce from managing q units of long-term assets. Assuming perfect competition between those investors, $G(q)$ also stands for the amount of cash the bank can raise if it sells q units of long-term assets in the market at date $t = 1$.

Assumption 1. *Function $G(.)$ satisfies the following conditions:*

$$G(0) \leq 0, \quad G'(q) < 0 \quad \textit{and} \quad G'(q)q + G(q) > 0 \quad \textit{for all} \quad q \geq 0$$

The first two conditions in Assumption 1 indicate that the cash flows generated by outside investors from redeploying the long-term asset is less than R and decreasing with the quantity they have to manage. Therefore, the price is decreasing with the volume of assets on sale. The second condition merely ensures that the total revenue from selling q units of long-term assets, i.e. $qG(q)$, is increasing with the quantity.

Liabilities and liquidity problem The bank finances its assets at date 0 by a fraction k of equity, the remaining fraction being demandable deposits. Demand deposits pay a gross rate of return normalised to 1 and give their holder the right to withdraw on demand. Denote by $\delta \in [0, 1]$ the fraction of depositors that turn out to have liquidity needs at date 1 and thus have to withdraw their deposits. 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 $F(.)$. The value of δ is realised at date 1. If the withdrawal amount is higher than the bank's liquid asset holdings, the bank can raise additional liquidity by selling its long-term assets.

Timing The timing of the model, which is summarised in Figure 1, is as follow. At date 0, given its liability structure, the bank optimally chooses its holdings of liquid assets c and long-term assets $1 - c$. At date 1, the fraction of depositors who withdraw is realised. If the bank's holdings of liquid assets are not enough to meet withdrawals, the bank will sell some of its long-term assets to raise additional liquidity. In the case where the bank cannot raise enough liquidity to repay its depositors who withdraw, it is liquidated. Otherwise, it continues to date 2 when long-term assets pay off and all remaining payments are settled.

2.2 Analysis

We analyse, in this subsection, the bank's optimal liquidity holdings at date 0. Our ultimate objective is to formulate predictions on the relationship between the bank's capitalisation and its engagement in liquidity transformation. Since in our setting, the bank's liability structure is taken as given, its choice of liquidity transformation is given by its choice of liquidity holdings *relative* to the size of its demand deposits. Therefore, we focus here on whether and how the bank's capital ratio affects its liquid asset holdings

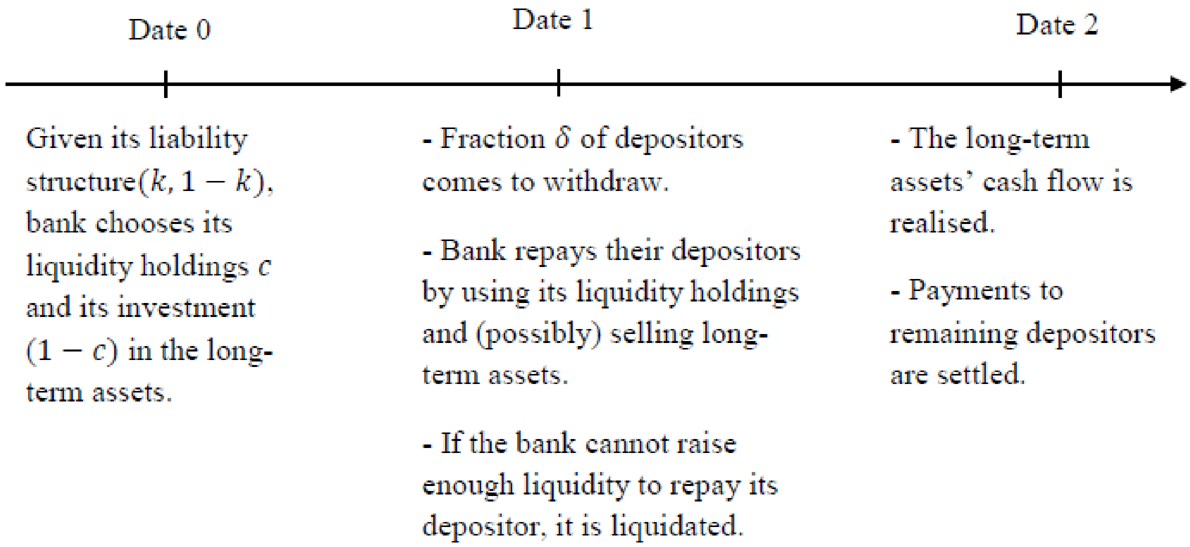


Figure 1: The timeline

and, through that, the probability that it fails following the liquidity shock. We proceed via backward induction. First, given the bank's liquidity holdings c, we determine the withdrawal cut-off level above which the bank will fail. Then we examine the bank's optimal liquidity holdings at date 0.

2.2.1 Bank's probability of being illiquid

At date 1, given c, the bank is in liquidity shortage when the realised value δ is such that

$$\delta(1-k) > c \tag{1}$$

or equivalently

$$\delta > \frac{c}{1-k} \tag{2}$$

We will henceforth refer to $\frac{c}{1-k}$ as liquidity shortage threshold. In that case, denote by $\beta \leq 1$ the fraction of long-term assets the bank must sell and by p the unit price of those assets. β and p are then jointly determined by the two following conditions:

$$\beta(1-c)p \geq \delta(1-k) - c \tag{3}$$

and

$$p = G\left[\beta(1-c)\right] \tag{4}$$

Condition (3) states that the proceeds from asset sales must cover at least the liquidity needs of the bank while Condition (4) specifies that the unit price of long-term assets is determined by the total cash flows that investors produce from redeploying the volume of assets they purchase.

Two observations are in order here. First, since liquid assets are less profitable than long-term assets and there is no further liquidity shock between date 1 and date 2, the bank has no incentive to sell more long-term assets than needed. In other words, in equilibrium, Condition (3) will never be satisfied with strict inequality. Second, if the fraction of depositors who withdraw at date 1 is too high, the bank may not be able to raise enough liquidity even after selling all of its long-term assets. This happens when Condition (3) cannot be satisfied even if $\beta = 1$.

Hence, when $\delta > \frac{c}{1-k}$, we have

$$\beta = min\left(1, \frac{\delta(1-k) - c}{(1-c)p}\right) \tag{5}$$

Plugging Result (5) into Condition (4), we obtain, in the case of liquidity shortage, the unit price of long-term assets as implicitly defined by the following equation[5]:

$$p = G\left[min\left((1-c), \frac{\delta(1-k) - c}{p}\right)\right] \text{ if } \quad \delta > \frac{c}{1-k} \tag{6}$$

Denote by $p^e(\delta, k, c)$ the price satisfying Equation (6). The cut-off value of δ - denoted by $\overline{\delta}(k, c)$ - above which the bank will be closed is then the solution to the following equation:

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

[5]Note that in the case of no liquidity shortage, there are no assets put on sale.

Lemma 1. *The default threshold $\overline{\delta}(k,c)$ is increasing in both k and c.*

Proof. See Appendix A.1 □

Lemma 1 is intuitive. Clearly, for any given k, if the bank holds more liquid assets, it can sustain higher withdrawals, which means that the default threshold is increasing with c. An increase in k also leads to an increase in $\overline{\delta}$ since a higher capital ratio reduces the size of demand deposits. This in turn implies that the same amount of liquidity can be used to meet a higher fraction of withdrawals.

2.2.2 Bank's optimal liquidity holdings

We are now ready to solve for the bank's optimal liquidity holdings. The bank will choose c to maximise its expected profits. At date 0, the bank's expected profit can be written as follows:

$$\begin{aligned}\Pi^B = &\int_0^{\frac{c}{1-k}} \left[(1-c)R + c - \delta(1-k) - (1-\delta)(1-k)\right] f(\delta)d\delta \\ &+ \int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \left[(1-\beta)(1-c)R - (1-\delta)(1-k)\right] f(\delta)d\delta\end{aligned} \tag{8}$$

The first term is the expected profit the bank will receive if its liquid asset holdings are 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 default threshold $\overline{\delta}(k,c)$, 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:

$$\begin{aligned}\Pi^B = &\left[R - 1 + k - c(R-1)\right] \\ &- \underbrace{\left[\int_{\frac{c}{1-k}}^{\overline{\delta}(k,c)} \left[\beta(1-c)(R-p^e\right] f(\delta)d\delta + \int_{\overline{\delta}(k,c)}^{1} \left[R - 1 + k - c(R-1)\right] f(\delta)d\delta\right]}_{\equiv A(k,c), \text{ i.e. the expected losses due to liquidity shortage}}\end{aligned} \tag{9}$$

In words, the bank's expected profit is equal to the expected profit it will receive if there is no potential liquidity problem at date 1 minus the expected losses it will incur due to liquidity shortage. The latter is the sum of two losses. If withdrawals are at the intermediate level, the losses come from the sale of a fraction of long-term assets at a price lower than their value. When withdrawals are high enough, the bank will be closed at date 1 and loses all the return of long-term assets together with its whole capital.

Expression (9) also makes clear the trade-off driving the bank's liquidity holding decision. On the one hand, the cost of holding liquidity is the foregone return of the long-term asset represented by the term $(-c(R-1))$ in the squared brackets of Expression (9). On the other hand, the benefit of holding liquidity lies in the reduction of the expected losses that the bank might suffer when early withdrawals are high. The following proposition characterises the bank's optimal liquidity holdings.

Proposition 1. *The bank's optimal liquidity holdings are given by the solution to*

$$-\frac{\partial A(k,c)}{\partial c} = R-1 \tag{10}$$

where

$$-\frac{\partial A(k,c)}{\partial c} = \frac{\partial \bar{\delta}}{\partial c}\left(k-(1-c)(1-p^e)\right)f(\bar{\delta}) + \int_{\frac{c}{1-k}}^{\bar{\delta}} \frac{R-p^e}{p^e} f(\delta)d\delta + \int_{\bar{\delta}}^{1}(R-1)f(\delta)d\delta \tag{11}$$

Proof. Equation (10) is the first order condition derived from the bank's optimisation problem using Expression (9) as the bank's expected profit. □

Intuition is straightforward. Since $A(k,c)$ is the expected losses the bank incurs if withdrawals at date 1 are higher than its available liquidity, the left hand side of Equation (10) represents the expected marginal benefits of holding liquidity to the bank. Therefore, Equation (10) is just the equalisation of the expected marginal benefit to the expected marginal cost of liquidity holdings.

2.3 Bank capitalisation and overall liquidity transformation

We now turn to examine the impact of a bank's capital on the degree to which it engages in liquidity transformation. The degree of liquidity transformation is determined by the mismatch between the liquidity of the assets and the one of liabilities. The higher the mismatch is (i.e. the less liquid the assets are relatively to the liabilities) the more likely the bank defaults following a liquidity shock. Therefore, in our model, we can use $F\left[\overline{\delta}(k,c)\right]$ - the probability that the bank survives the liquidity problem - as proxy for the bank's overall degree of liquidity transformation. Precisely, the degree of liquidity transformation is decreasing with $F\left[\overline{\delta}(k,c)\right]$.

To investigate the effects of a bank's capital on the overall degree of liquidity transformation, we proceed in two steps. First, we analyse the impact of bank capital on asset liquidity. Then we study its implications for the bank's overall degree of liquidity transformation.

2.3.1 Bank capitalisation and asset liquidity

The following corollary states the result on the link between the bank's capital ratio and its liquidity holdings:

Corollary 1. *The impact of k on the bank's optimal liquidity holdings c^* has the same sign as its impact on the expected marginal benefits of liquidity holdings, i.e.*

$$\frac{dc^*}{dk} \lesseqqgtr 0 \Leftrightarrow -\frac{\partial^2 A(k,c^*)}{\partial c \partial k} \lesseqqgtr 0 \tag{12}$$

Proof. See Appendix A.2 □

Given Corollary 1, to understand the channels through which a bank's capital affects its liquidity holdings, it is useful to explore how a bank's capital ratio k influences the expected marginal benefits of holding liquidity, i.e. $-\frac{\partial A(k,c)}{\partial c}$. As explained above, the benefits of holding liquidity for the bank lie in the reduction of the expected losses resulted from liquidity shortage. From Expression (11), we see that higher liquidity holdings reduce these losses in two ways.

First, looking at the first term on the right hand side of Expression (11), we see that higher liquidity holdings are beneficial by shifting the default boundary and so reducing the probability of losing its capital for the bank. Clearly, a higher capital ratio increases the benefit of higher liquidity holdings since it makes the bank lose more in the case of default.

Second, in the region where the bank is in liquidity shortage, but not in default, higher liquidity holdings are useful since it reduces the volume of assets being sold at a discounted price, which in turn reduces the losses from fire sales. A higher capital ratio affects this benefit by impacting the liquidity shortage threshold $\frac{c}{1-k}$. Precisely, a higher capital ratio increases this threshold for any given c, which reduces the probability of being short on liquidity for the bank. Hence, a higher capital ratio decreases this benefit of holding liquidity.

We refer to the first effect of bank capital on the marginal benefit of liquidity holdings as the *"skin-in-the-game"* effect since it reflects the impact of the former on what the bank will lose in case of failure. The second effect is referred to as the *"liquidity-demand"* effect since it expresses the impact of bank capital on the need for holding liquidity to avoid falling into the liquidity shortage situation. Through the first effect, a higher capital ratio induces the bank to hold more liquidity. However, through the second effect, it leads the bank to hold less liquidity. The overall effect of bank capitalisation on liquidity holdings will therefore depend on which of the two effects is stronger.

2.3.2 Bank capitalisation and overall liquidity transformation

As explained above, the bank's overall degree of liquidity transformation is measured, in our theoretical setup, by the bank's survival probability $F\left[\overline{\delta}(k,c)\right]$. Hence, we examine here how k affects $\overline{\delta}(k,c^*)$. From Equation (7), using implicit differentiation rule, we can decompose the impact of k on $\overline{\delta}(k,c^*)$ as follows:[6]

[6]See Appendix A.3 for detailed derivations.

$$\frac{\partial\overline{\delta}}{\partial k} = \frac{\overbrace{\overline{\delta}}^{\geq 0} + \overbrace{(1-c^*)\frac{\partial p^e}{\partial k}}^{\geq 0} + \overbrace{(1-p^e)\frac{dc^*}{\partial k}}^{\geq 0 \quad or \quad \leq 0}}{1-k-\underbrace{(1-c^*)\frac{\partial p^e}{\partial\delta}}_{\leq 0}} \tag{13}$$

Two points are in order. First, the bank's capital ratio has three effects on its degree of liquidity transformation. The first effect - represented by the term δ in the numerator of Expression (13) - 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 the bank needs to sell, thus increasing the price. The third effect arises via the impact of the bank's capital ratio on its asset liquidity.

Expression (13) illustrates that it would be misleading to assess the bank's vulnerability to liquidity problems by looking solely at asset liquidity. For example, we see clearly from Expression (13) that even if a higher capital ratio induces the bank to hold less liquid assets (i.e. $\frac{dc^*}{dk} < 0$) this does not necessarily mean that the bank's resilience to a liquidity shock will decrease. That is the case only if the impact of this reduction is stronger than the two positive effects of capital on price and the liability structure.

2.3.3 Numerical example

The analysis so far shows that the impact of bank capital on its liquidity, either its asset liquidity or its overall degree of liquidity transformation, is more than trivial. It includes multiple effects that can go in opposite directions, which makes the sign of the overall effect dependent on the relative strength of individual effects.

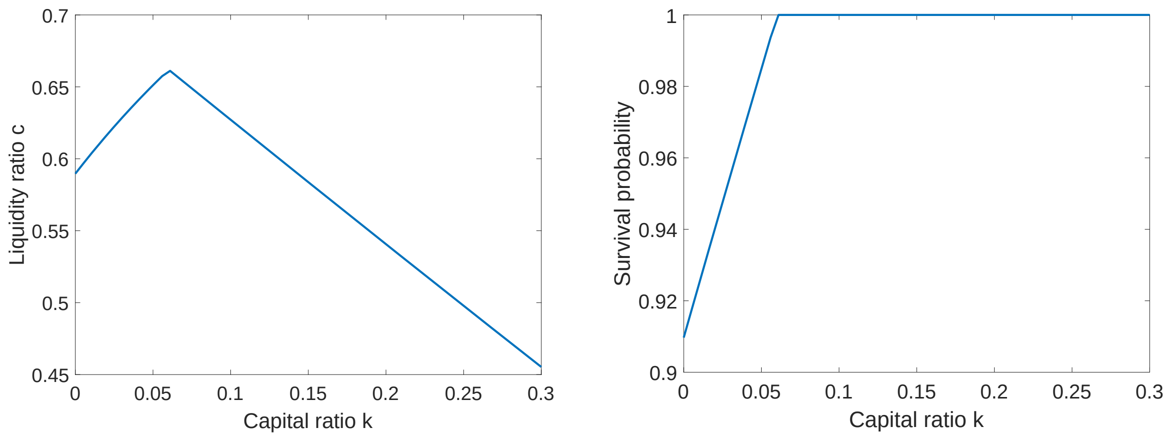
To get some additional insight into the potential sign of the overall effect, since the first order condition (10) cannot generally be solved for c in closed form, we consider here a simple numerical example in which δ is uniformly distributed and the function $G(.)$

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 survival probability 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

In our simple numerical example, there exists an inverted U-shaped relationship between bank capital and liquidity holdings, which implies that the *skin-in-the-game* effect dominates when k is low while the *liquidity-demand* effect dominates when k is large enough. This occurs because when k is sufficiently low, 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. Therefore, 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. In terms of the impact of bank capital on the bank's overall liquidity profile, our numerical example suggests that higher capital ratios induce banks to engage less in liquidity transformation.[7]

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

2.4 Discussion of main assumptions and generality of results

Return on deposits We assume in our framework an exogenous return on deposits. This can be justified by frictions that prevent or demotivate depositors to price bank risk properly. In the case of retail deposits, we believe that this assumption is a good reflection of reality due to the existence of explicit government guarantees for this type of deposit in almost all advanced economies. In the case of wholesale deposits, one can imagine many factors that could lead to the mispricing of banks' debt such as opaqueness of banks' assets. Note that it is not important for our results that the deposits' return is completely insensitivity to banks' risk. All we require is some non-zero degree of mispricing, which we believe is good representation of reality.

The withdrawal problem The size of withdrawals is assumed in our setup to be exogeneously determined by depositors' demand for liquidity. We thus abstract from the issue of endogenous runs where the fraction of withdrawals could depend on a bank's balance sheet characteristics such as a bank's level of capital. Taking this into account could generate additional effects of capital on the stability of banks' liabilities via its impact on the run probability. These additional effects are of the same nature as our *liquidity-demand* effect and accounting for those would affect the strength of this effect. If higher capital reduces the probability of runs as suggested by Vives (2014), it will reinforce our *liquidity-demand* effect.

Exogeneity of liabilities In our model, we assume exogenously the liability structure of the bank, which implies that the bank is assumed not to adjust the composition of its debt following a change in its capital ratio. Put differently, this assumption implies that banks would manage their liquidity profile mostly by adjusting their asset side. As shown in Section 3.4.3 and 3.4.4 below, this assumption appears to reflect the banks' strategy in reality.

3 Empirical analysis

The theoretical analysis, even in a very simple framework, highlighted that the link between bank capital and liquidity transformation is quite involved since it is the result of different effects with different signs. This demonstrates the empirical relevance of the question. Using numerical analysis, we have proposed two predictions on the link between bank capital and its asset liquidity as well as its overall degree of liquidity transformation. We investigate in this section whether those predictions are supported by the data. To get started, we first determine the set of banks to be used in our analysis. Then we identify the empirical counterparts to our model's key variables. Finally, we set up the empirical methodology and report the results.

3.1 Sample formation

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 with semi-annual frequency. It is an unbalanced panel that covers a period from 1989H2 to 2013H2. It contains information on different balance sheet items of banks including their actual and required levels of capital at the group level.

UK regulatory capital regime During our sample period, all banks in the UK (i.e. UK-owned banks and resident foreign subsidiaries) are subject to a regulatory policy regime that imposes, on top of the Basel Pillar 1 minimum capital requirements, an additional requirement called the Individual Capital Guidance (ICG). This ICG is bank-specific, time-varying and reviewed every 18 - 36 months. It was set in terms of an additional percentage of Pillar 1 requirements banks were asked to meet, or an additional absolute amount of capital in Sterling they must have, or both. In our dataset, the ICG variable is reported as the absolute amount of required capital resources. This variable, together with information on risk-weighted assets (RWAs) and total assets, allows us to compute two banks' required capital ratios, namely the ratios of total required capital resources over RWAs and over total assets.

Our sample To construct our sample, we follow Francis and Osborn (2012) and apply the following filtering criteria to the above dataset. First, to deal with mergers and acquisitions (M&A) activities that are identified using Dealogic and information in banks' annual reports, we create a new successor bank after such events. For material changes that do not pertain to M&A activities, such as the purchase or divestiture of a business line, we create a new entity when assets fall or rise by more than 30% over 6 months.[8] Second, we drop observations when those observations represent an increase or a decrease of capital or loans by more than 50% over a half-year. Third, we drop outlier values such as regulatory capital ratios above 50% or below 8%, ratios of liquid assets over total assets above 100% or below 0, ratios of RWAs over total assets above 100%. Fourth, as in Bahaj and Malherbe (2016), only changes in the requirement that are greater than or equal to 5bp of the bank's total RWAs are counted. This is because we cannot track directly all communications from supervisors where banks' ICG were adjusted. Restricting to big changes therefore helps to make sure that changes in banks' capital are the result of the changes in the requirements imposed by supervisors instead of changes in banks' balance sheets. 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 drop of data points from 3440 to 2514.[9] Finally, we conduct the analysis at the highest level of UK consolidation for each bank. We keep foreign subsidiaries as well as banks with loans or deposits below 10% of assets because those banks are also subject to ICGs and equally exposed to liquidity risk.

Our final sample is an unbalanced panel that has 2514 semi-annual observations of 154 banks. Table 1 shows summary statistics for the banks in our sample. The variation in total assets as well as in other balance sheet items such as loans, wholesale debt or off-balance sheet commitments is very large, which shows that our sample includes banks of various sizes and business models. The variation in our key variable of interest - the ICG over RWAs - is also large. The mean of this ratio is 11.1%, the standard deviation is 2.5%, the minimum value is 8% and the maximum is 19.3%.

3.2 Main empirical variables

We describe here the way we construct our main independent variable - bank capital - and our dependent variables - bank liquidity.

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

[9] The loss of a third of observations in 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
ICG over RWAs	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 ICG over RWAs	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.

3.2.1 Measure of banks' capital

In our theoretical model, the bank's capital ratio k stands for the *actual* capital ratio the bank has. An obvious empirical counterpart for k in the data is the ratio of a bank's *actual* equity resources over total assets or over RWAs. However, in our regression setting, the use of banks' *actual* capital ratios will subject our analysis to an endogeneity problem, which prevents any claims to causal effects in the link between bank capital and bank liquidity. Therefore, in the empirical analysis, we use banks' *required* capital ratios as a proxy for banks' *actual* capital ratios. In that way we are able to exploit the exogeneity of changes in the ICG.

Clearly, a necessary condition for the validity of using the required capital ratio as a proxy for the actual capital ratio is that the regulatory capital requirements must continuously act as binding constraints on banks' capital ratio choices. Binding capital requirements however do not mean that banks always hold capital at the level of the regulatory requirement. Rather, binding capital requirements merely imply that banks adjust actual capital ratios in accordance with the changes in the requirements. In general, binding capital requirements are perfectly compatible with a positive 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) examine 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 is consistent with 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 3 illustrates this finding in our dataset.[10]

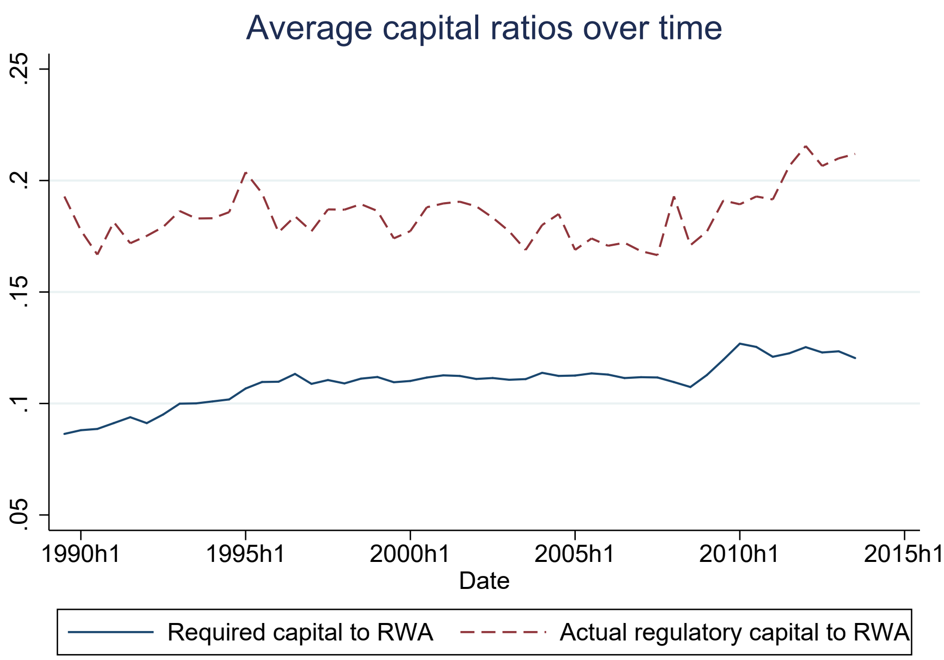


Figure 3: Evolution in actual and required capital ratios

In terms of variation of ICG over time, we identified in our sample 500 changes

[10]We also find a significant positive correlation between banks' actual capital ratios and their required ones. Those results are available upon request.

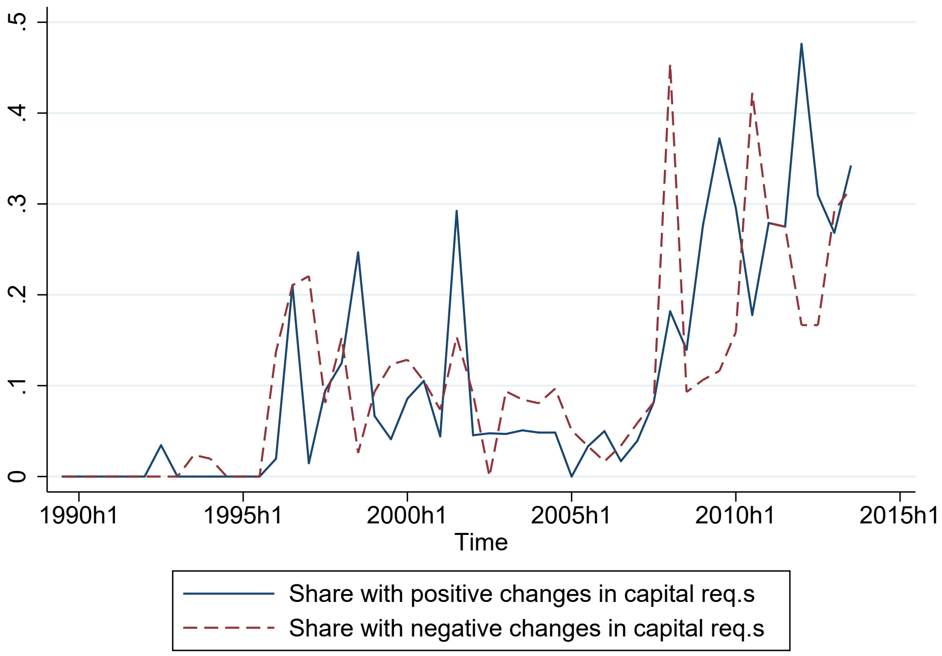


Figure 4: Bank-level capital requirement changes over time

represented in Figure 4. There is heightened changes in the late 1990s and early 2000s which largely reflects efforts of supervisors to improve consistency between different types of firms after the creation of the Financial Services Authority (FSA) in 1997. During and after the 2008 financial crisis, the ICG has been used more frequently and more broadly, signalling more pro-active supervision.

3.2.2 Measures of bank liquidity

Measures of banks' asset liquidity The liquid assets in our theoretical setup have two main features. They are less profitable but readily available or can be sold to raise money without significant impact on price. Therefore the most obvious balance sheet items that could serve as proxies for our liquid assets are level 1 high quality liquid assets (HQLA), such as cash, central bank reserves or government bonds. The sum of these assets normalised by banks' total assets is hereafter referred to as *NarrowAssetLiq*.

We also consider a broader measure of banks' liquid assets holdings named *BroadAssetLiq* which includes, beside level 1 HQLA, corporate debt securities, corporate bonds, covered bonds and some residential mortgage backed securities. The reason for which the latter types of assets could also be treated as liquid assets is that in general, there exists liquid secondary market for them. This make them tradable and can constitute a source of liquidity for banks as well.

Measure of banks' overall liquidity transformation The theoretical analysis highlights that looking only at the liquidity of banks' assets to assess their vulnerability to liquidity shocks or their degree of liquidity transformation could be misleading. A measure of banks' liquidity transformation needs to take into account the *relativity* of liquidity between both sides of banks' balance sheets. For this purpose, we use a variant of the so-called 'liquidity creation' measure developed by Berger and Bouwman (2009) - henceforth referred to as *BBLiqIndex* - as our measure for the extent of banks' liquidity transformation. This measure gauges the mismatch between the liquidity of banks' assets and the liquidity of their liabilities.[11]

Formally, the *BBLiqIndex* is defined as follows:

$$BBLiqIndex = \frac{\sum_i Assets_i \times weight_i + \sum_j Liabilities_j \times weight_j}{TotalAssets + OffBSCommitments\&Guarantees} \tag{14}$$

where assets and liabilities are measured by their notional value. The construction of this measure proceeds in two steps.

First, banks' assets and liabilities including off-balance sheet items are classified into three liquidity buckets, namely liquid, semi-liquid and illiquid. This classification is based on, for the liability side, the ease, cost and time for banks to meet creditors' demand, and, for the asset side, the ease, cost and time to raise 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, excluding residential mortgages[12], are considered illiquid since they are difficult or impossible to be sold on a secondary market, whereas gilts are liquid assets as there exists a large and liquid secondary market for them. Due to a less granular balance sheet break-down, we diverge

[11] We do not use a proxy for the Basel III Net Stable Funding Ratio (NSFR) since the granularity of our balance sheet data does not allow us to build a meaningful proxy.

[12] Mortgages are excluded from the illiquid bucket and classified as semi-liquid assets since in general, banks can sell these assets via securitisation.

Table 2: Construction of *BBLiqIndex*

	Assets	
Illiquid assets (w = 0.5) Loans except residential mortgages	*Semi-liquid assets* (w = 0) All other assets	*Liquid assets* (w = -0.5) Liquid assets
	Liabilities plus equity	
Liquid liabilities (w = 0.5) All liabilities except capital	*Semi-liquid liabilities* (w = 0)	*Illiquid liabilities and equity* (w = -0.5) 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 our classification of assets and liabilities into different liquidity buckets together with their corresponding liquidity weights. Liquid assets includes high quality liquid assets such as 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 partly-paid shares and securities, NIFs and RUFs, endorsements of bills, and other commitments.

slightly from the classification used by Berger and Bouwman (2009). In particular, we make some changes to the treatment of off-balance-sheet commitments and guarantees. These adjustments are unlikely to have material impacts.[13] Table 2 provides the details on the types of assets included in each bucket.

Then, a liquidity weight is assigned to each category of assets and liabilities. The weight is determined so that if, for example, banks use one unit of liquid liabilities to finance one unit of illiquid assets, then one unit of liquidity transformation is created. Therefore, for this principle being satisfied in Formula (14), assets in the illiquid bucket

[13] We control for the treatment of off-balance sheet commitments by using a variation of our *BBLiqIndex* with the exclusion of off-balance sheet commitments in the robustness analysis (see Table 8). It does not change our main result.

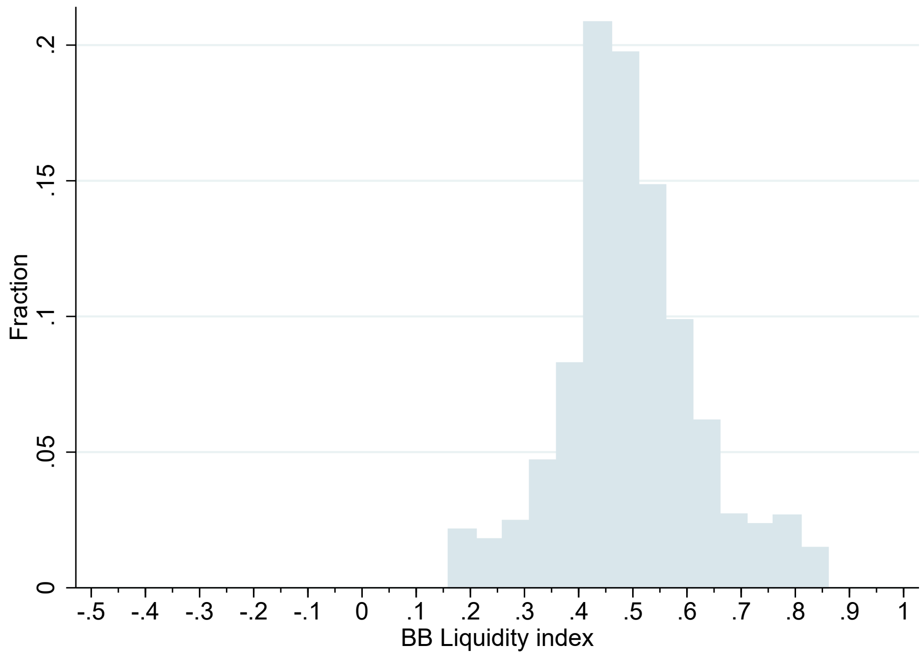


Figure 5: Distribution of our BB Liquidity Index

and liabilities in the liquid bucket are assigned a weight equal to 0.5. When semi-liquid liabilities are used to fund semi-liquid assets, no liquidity transformation emerges, which implies that assets and liabilities in the semi-liquid bucket have a zero weight. When banks finance one unit of liquid assets with one unit of illiquid liabilities, one unit of liquidity transformation is destroyed. This means that liquid assets and illiquid liabilities get a weight equal to -0.5. Table 2 summarises the weights assigned to each asset and liability category.

Given the construction approach, we see that the $BBLiqIndex$ will take the value from -1 to 1 and the higher it is, the bigger the banks' degree of liquidity transformation. A positive value of the $BBLiqIndex$ means that banks' assets are relatively less liquid than banks' liabilities, while a negative value implies that banks' assets are more liquid than their liabilities.

Figure (5) represents the distribution of the $BBLiqIndex$ among banks in our sample. We see that all banks have a positive $BBLiqIndex$, which imply that they all have positive exposures to liquidity shocks. This is consistent with the assumption in our theoretical framework that the role of banks is to provide liquidity to customers.

3.3 Econometric methodology

3.3.1 Specification

Using bank-level data, we run a series of regressions of the following form:

$$LiqMeasure_{i,t} = \gamma_1 + \gamma_2\ CapReqMeasure_{i,t} + \gamma_3\ Controls_{i,t-1} + \upsilon_i + time_t + \varepsilon_{i,t} \quad (15)$$

The subscript i represents a bank and t represents the time-period. $LiqMeasure$ represents our measure of bank liquidity. Our main measure for liquidity transformation is *BBLiqIndex*, but we also run other regressions with various measures of bank liquidity, such as *NarrowAssetLiq* or *BroadAssetLiq* for asset liquidity. $CapReqMeasure$ is our required capital ratio, which can be expressed as a ratio over RWAs or over total assets. $Controls$ include a set of bank level variables that we, based on the literature, add to control for bank specific characteristics. Specifically, they are the log of total assets, return on assets (ROA), impairments scaled by total loans, RWA density,[14] and the liquidity regime that banks are subject to. Control variables are lagged by one period to reduce potential endogeneity problems. We estimate the model using bank fixed effects to control for time-invariant differences across banks, such as business models, that are not captured by our other control variables. 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.

Control for liquidity regimes. In the period we study, UK banks were also subject to some liquidity requirements as detailed in Appendix A.4. 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 called the Individual Liquidity Guidance covering almost all banks.[15] We control for the impact of these regimes on banks' liquidity decisions by including dummies for past liquidity regimes in our regression equations. For example, to control for the Building

[14] In our sample, these four variables are not strongly correlated (results available upon request). Hence, the simultaneous inclusion of them should not create collinearity problems.

[15] See Banerjee and Mio (2017) for details on banks that are exempted.

Societies regime, we add a dummy that is equal to 1 for banks that were building societies in the period prior to 2010, and 0 otherwise.

3.3.2 Identification

In practice, bank capital and liquidity are to some extent jointly determined. To mitigate this potential endogeneity problem and establish causality, our identification strategy relies on using banks' required capital ratios as our proxy for banks' actual capital ratios. This allows us to exploit the changes in the ICG that can be claimed to be exogenous. Note that the key condition for a causal interpretation to be valid in our analysis is that these changes 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 the ICG in the period we study.

For the period before the financial crisis, as described in Turner (2009), 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 (2016) were able to track some of the confidential letters sent by supervisors to banks notifying them of their new capital guidance, and 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"*.

Moreover, 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:[16]

"The Supervision Team commented to the Review Team that analysis of liquidity returns

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

was not a focus of its supervision during the Review Period[17] *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..."*

For the period 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.[18] 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 thus 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.

3.4 Empirical results

The empirical results will be presented as follows. We first present our baseline analysis on the relationship between bank capital and liquidity transformation. We then assess the link between bank capital and liquid asset holdings to test whether both our theoretical predictions hold. Lastly, we explore in more detail how banks adjust their balance sheet, if large banks differ from smaller banks and if the 2008 financial crisis changed the relationship between bank capital and liquidity transformation.

3.4.1 Bank capital and liquidity transformation

This section explores the link between banks' capitalisation and the extent in which they engage in liquidity transformation. The numerical simulation of our theoretical model suggested that this relationship should be negative, and we indeed find a negative relationship. Table 3 contains our results.

In the first two columns, we examine the impact of *contemporaneous* changes in banks'

[17] The Review Period for RBS failure was from the beginning of 2005 to October 2008
[18] See Appendix A.4 for a summary of the past liquidity regime in the UK

capital on their degree of liquidity transformation. The negative and significant coefficients we find imply that higher capital ratios induce banks to reduce their liquidity transformation. The main difference between the specification of these two columns is that in Column 1, we include the RWA density as a control, whereas in Column 2, we do not. The goal of making this comparison is that following an increase in the risk-weighted capital requirement, banks can shift their portfolio towards assets with a lower risk-weight to reduce their RWAs. These adjustments are purely for the purpose of reducing the level of credit risk and so, one may argue, the impact on our liquidity risk measure is simply a byproduct of assets with lower risk-weights, for example government bonds, also generally being more liquid. Including the RWA density allows us to control for this portfolio rebalancing motive.[19] We see that when the RWA density is added as a control, although the absolute value of the coefficient of interest is smaller, it remains statistically significant. This suggests that changes in the capital requirement affect liquidity transformation beyond the impact of rebalancing the portfolio towards assets with lower credit risk, which is consistent with our theoretical prediction.

To interpret the magnitude of the coefficient, it is important to remember that our capital measure is a percentage while our liquidity index is scaled between -1 and 1. Based on Equation (15), we find that an increase of 1% in the risk-weighted capital requirement will lead our liquidity index to decrease, using the result in the first column, by 0.804%.

In the last three columns of Table 3, we explore whether changes in banks' capital have long term effects on banks' liquidity transformation. We find that the effect is rather persistent with the existence of a significant impact up to 1.5 years later. Comparing the intertemporal changes between the coefficient of the RWA density and the one of our capital measure, we see that while both the statistical significance and magnitude of the former is decreasing overtime, the statistical significance of the coefficient of our capital measure remains the same and its magnitude tends to increase. This suggests that the impact through the above-described rebalancing portfolio motive is more likely to happen in the short-term, whilst the additional effect on liquidity risk is more long lasting.

[19] Note that in our theoretical setup, we isolate the liquidity problem from the problem of credit risk by assuming that both liquid and illiquid assets are safe. Hence, our theoretical prediction only concerns liquidity risk.

Table 3: Bank capital and liquidity transformation

	Dependent variable: Liquidity transformation - *BBLiqIndex*				
	(1)	(2)	(3)	(4)	(5)
Independent variables					
CapReqMeasure$_t$	-0.804**	-1.046***			
	(0.336)	(0.306)			
CapReqMeasure$_{t-1}$			-0.879**		
			(0.378)		
CapReqMeasure$_{t-2}$				-0.947**	
				(0.363)	
CapReqMeasure$_{t-3}$					-1.010**
					(0.387)
RWA Density$_{t-(k+1)}$	0.177***		0.163***	0.128**	0.0930*
	(0.0509)		(0.0510)	(0.0496)	(0.0522)
ROA$_{t-(k+1)}$	-0.134	-0.0446	-0.219	-0.342	-0.221
	(0.253)	(0.241)	(0.312)	(0.316)	(0.467)
Scaled Impairments$_{t-(k+1)}$	0.198**	0.233**	0.0814	0.0267	0.0301
	(0.0900)	(0.0964)	(0.101)	(0.123)	(0.129)
ln(Total Assets)$_{t-(k+1)}$	0.0178	0.00442	0.0127	0.00575	-0.00679
	(0.0129)	(0.0134)	(0.0125)	(0.0133)	(0.0168)
Constant	0.345***	0.575***	0.405***	0.491***	0.623***
	(0.116)	(0.110)	(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	0.869	0.860	0.875	0.872	0.863
Adj. R2 within	0.130	0.0701	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 results on the link between banks' capitalisation and their liquidity transformation from the regression: $LiqMeasure_{i,t-k} = \gamma_1 + \gamma_2\ CapReqMeasure_{i,t-k} + \gamma_3\ Controls_{i,t-(k+1)} + \upsilon_i + time_{t-k} + \varepsilon_{i,t-k}$. The dependent variable is our measure of banks' liquidity transformation *BBLiqIndex*. The main regressor is our measure of capital requirements expressed as a required percentage of capital over total regulatory RWAs. All control variables have one extra lag as compared to our capital measure. For example, when our capital measure is lagged twice, all control variables are lagged three periods.

3.4.2 Bank capital and asset liquidity

We now consider the impact of banks' capital on their asset liquidity. Our theoretical model suggested that there should exist an inverted U-shaped relationship in the data between banks' liquid asset holdings and their capital.

We estimate the following variant of our regression to test this:

$$LiqMeasure_{i,t} = \beta_1 + \beta_2\ CapReqMeasure_{i,t} + \beta_3\ CapReqMeasure^2_{i,t} + \beta_4\ Controls_{i,t-1} + u_i + time_t + \epsilon_{i,t} \tag{16}$$

The dependent variable is one of our measures of asset liquidity described in Section 3.2.2. We also consider the ratio of all liquid assets used in the construction of the *BBLiqIndex* to total assets as another alternative measure of asset liquidity. We use the leverage ratio as the required capital ratio since it is closer to our theoretical capital ratio which is not risk-sensitive. Since the ICG can be expressed either in RWA space or in Sterling, we derive the implicit leverage requirement by multiplying the ICG with a bank's RWA density.

Table 4 reports our results. Consistently across all three alternative measures of asset liquidity, we find a negative and statistically significant coefficient for the squared term of our capital measure. This is in line with our prediction of an inverted U-shaped relationship. To identify the turning point, we compute the first derivative of our regression equations and find that, in all three specifications, this point is situated around a leverage ratio of 10%.[20] Therefore, banks with an implicit leverage ratio requirement above 10% tend to reduce their liquid assets holdings following an increase in this requirement. We observe that these banks have riskier assets - the average RWAs of these banks is 86% compared to the average RWAs of 55% in our whole sample. They also seem to have less deposits (34% instead of 54%), and 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 banks' actual leverage ratios (on average around 4-5% for large UK banks), most UK banks are not in the region where they would reduce

[20]The plot of these derivatives can be found in Appendix A.5.

Table 4: Bank capital and asset liquidity

Independent variables	$NarrowAssetLiq$ (1)	$BroadAssetLiq$ (2)	Liquid assets in $BBLiqIndex$ (3)
CapReqMeasure_t	1.212**	2.668**	2.343*
	(0.474)	(1.172)	(1.210)
CapReqMeasure_t^2	-6.205**	-13.63**	-11.86**
	(2.438)	(5.430)	(5.489)
RWA Density_{t-1}	-0.0335	-0.0799	-0.0691
	(0.0263)	(0.0684)	(0.0648)
ROA_{t-1}	-0.299	-0.312	-0.294
	(0.203)	(0.321)	(0.309)
Scaled Impairments_{t-1}	-0.0593	-0.369***	-0.262**
	(0.0658)	(0.142)	(0.114)
$\ln(\text{Total Assets})_{t-1}$	-0.00727	0.0240	0.0246
	(0.00912)	(0.0194)	(0.0185)
Constant	0.0832	-0.138	-0.120
	(0.0777)	(0.178)	(0.168)
Methodology	FE	FE	FE
Liquidity regimes	YES	YES	YES
Observations	1,984	1,984	1,984
Adj. R2	0.751	0.726	0.759
Adj. R2 within	0.0715	0.0746	0.0466
Banks	154	154	154

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

Note: This table shows our results for the relationship between banks' capital and their asset liquidity from the regression: $LiqMeasure_{i,t} = \beta_1 + \beta_2\ CapReqMeasure_{i,t} + \beta_3\ CapReqMeasure_{i,t}^2 + \beta_4\ Controls_{i,t-1} + u_i + time_t + \epsilon_{i,t}$. In column (1), the dependent variable is our measure of asset liquidity *NarrowAssetLiq* while in Column (2) it is *BroadAssetLiq*. Column (3) displays the regression results when the dependent variable is the liquid assets used in the construction of the *BBLiqIndex*. The main regressor is our banks' required capital ratio defined as the ratio of total required capital resources overs total assets.

their liquid asset holdings following an increase in capital. We find that only 10% of our observations, and 27 banks that are quite small[21] have a leverage ratio above 10%.

3.4.3 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 (15) and replace the dependent variables by the six main unweighted components of the *BBLiqIndex*: 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 their loans.

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. This empirical finding supports the assumption in our theoretical setting that the liability structure of the bank is taken as exogeneous to changes in its capital.

3.4.4 Heterogeneity

So far, all our empirical findings are in line with our theoretical hypotheses. In this subsection, we go beyond the theory to exploit further heterogeneity existing in our dataset. Given that the two main advantages of our sample are a long time-series and big

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

Table 5: Banks' adjustment channels

Independent variables	Liquid assets (1)	Semi-liquid assets (2)	Illiquid assets (3)	Deposits (4)	Wholesale funding (5)	Off-balance sheet (6)
CapReqMeasure_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)
Scaled Impairments_{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)
ln(Total $\text{Assets})_{t-1}$	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 our *BBLiqIndex*: 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.

variation in banks' asset size, we focus here on exploring whether the impact of banks' capital on their liquidity transformation differs across banks of different sizes and across pre- and post-crisis periods. To do so, we further decompose the coefficient γ_2 in Equation (15) using a relevant dummy variable Z. We thus estimate the following equation:

$$BBLiqIndex_{i,t} = \gamma_1 + (\gamma_3 + \gamma_4\ Z_{i,t})\ CapReqMeasure_{i,t} + \gamma_5\ Z_{i,t} + \gamma_6\ Controls_{i,t-1} + \upsilon_i + time_t + \varepsilon_{i,t}, \tag{17}$$

Pre-crisis vs. post-crisis To study whether banks' behaviour differs significantly between two periods, the dummy Z is defined as having value 1 for the period before the crisis (i.e. up to and including 2006) and 0 otherwise. The result is shown in the last column of Table 6.

The coefficient on the variable capital requirement does not change compared to our main regressions shown in Table 3. Moreover, the coefficient on the interaction term is not statistically significant. This suggests that the relationship between bank capital and liquidity transformation is not significantly different in the period after 2007 compared to the period before the crisis. However, 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. Therefore, 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.

Small banks vs. big banks We test whether there are any significant differences in the behaviour of small and large banks. For this analysis, the dummy Z takes value 1 for banks that are classified as big banks in our sample and 0 otherwise. Due to our long time series, we cannot simply define big banks as the largest banks using the last period of our sample. Instead, we consider two alternatives to define big banks. First, we identify the 10 largest banks at each period and count all of them as big banks. In this

Table 6: Bank size and 2008 crisis

	Dependent variable: Liquidity transformation - $BBLiqIndex$				
Independent variables	(1)	(2)	(3)	(4)	(5)
CapReqMeasure_t	-0.956***	-0.964***	-0.965***	-0.725**	-0.767***
	(0.354)	(0.358)	(0.364)	(0.346)	(0.274)
$\text{CapReqMeasure}_t * I_{largestbanks1}$	1.853**				
	(0.880)				
$\text{CapReqMeasure}_t * I_{largestbanks2}$		1.750**			
		(0.826)			
$\text{CapReqMeasure}_t * I_{largestbanks3}$			1.415**		
			(0.676)		
$\text{CapReqMeasure}_t * TotalAssets$				0.0857	
				(0.0869)	
$\ln(\text{Total Assets})_{t-1}$				0.00628	0.0180
				(0.0176)	(0.0130)
$\text{I}_{largestbanks3}$			-0.153**		
			(0.0687)		
$\text{CapReqMeasure}_t * I_{year<2007}$					-0.0799
					(0.395)
Constant	0.479***	0.474***	0.515***	0.484***	0.347***
	(0.0551)	(0.0543)	(0.0573)	(0.0545)	(0.118)
Control included	YES	YES	YES	YES	YES
Methodology	FE	FE	FE	FE	FE
Liquidity regimes	YES	YES	YES	YES	YES
Observations	2,000	2,000	2,000	2,000	2,000
Adj. R2	0.871	0.871	0.870	0.870	0.869
Adj. R2 within	0.140	0.139	0.136	0.131	0.130
Banks	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 the main drivers of the relationship between banks' capital and their liquidity transformation. $I_{largestbanks1}$ equals 1 for a bank if it is always in the top ten by total assets for the whole period of our sample, 0 otherwise. $I_{largest_banks2}$ equals 1 for a bank if it is always in the top 15 by total assets for the whole period of our sample, 0 otherwise. $I_{largest_banks3}$ equals 1 for a bank if it is in the top ten by total assets, even if for only one period, 0 otherwise. Therefore, in Columns (1) to (3), we are presenting results when the capital requirement measure is interacted with a dummy that take the value of 1 if banks are among the largest banks in our sample. We do not include total assets in the control variables in the first three columns to avoid possible collinearity with our dummy variables capturing large banks. Column (4) reports the result when we interact our capital requirement measure with banks' total assets. Finally, in Column (5), we display the results when we interact our capital requirement measure with a dummy variable that takes the value of 1 for years before 2007 and 0 otherwise.

way, our group of big banks is composed of 46 banks. Second, we count as big banks only banks that are always among the 10 largest banks throughout the whole time span of our sample. This definition is our preferred one since it excludes banks that switched between the two groups (small- and big-banks) and leads to a more stable group of 17 big banks. The reason for having more than 10 banks is because, as explained above, we create a new bank every time a bank undergoes a significant change such as a merger. Finally, we construct a third measure similar to the second definition but we expand to the 15 largest banks. We do not include total assets in the control variables in the regressions using those dummy variables to avoid possible collinearity.

The result for the three alternative definitions of big banks is reported in the first three columns of Table 6. The coefficient on our capital requirement variable is still negative and of a similar magnitude as the one in Table 3. But the coefficient on the interaction term is significant and positive, which suggests that the behaviour of the largest banks is significantly different from that of small banks.[22] This result is analogous to the finding of Berger and Bouwman (2009). Interestingly, when we interact our capital requirement measure with total assets, as shown in Column 4 of Table 6, the interaction term is not significant. This difference as compared to the case of the top biggest banks suggests that the effect of size on the interaction between bank capital and bank liquidity is not continuous: size seems to matter only above a certain threshold.

When we compute, for the subset of largest banks, the total effect of capital on liquidity transformation (i.e. the sum of the coefficient of the capital variable and of the coefficient on the interaction term), we find that it is insignificant for all of our three definitions of large banks. This implies that for the largest banks in our sample, although the relationship between capital and liquidity is significantly different from the rest of the sample, it does not seem to be statistically significantly different from zero. This suggests that for large banks, more capital does not affect liquidity risk. In other words, capital and liquidity are not substitutes for large banks.

In table 7, we breakdown the components of our $BBLiqIndex$ and also examine how large banks defined by our preferred definition (i.e. banks that are always among the 10 largest banks) adjust to an increase in capital requirements as compared to small

[22]These results are also unchanged if we consider top 20 or top 7 instead of top 10 or 15.

Table 7: Adjustment channels of small vs. large banks

Independent variables	Narrow Assets (1)	Liquid assets (2)	Semi-liquid assets (3)	Illiquid assets (4)	Deposits (5)	Wholesale funding (6)	Off-balance sheet (7)
CapReqMeasure_t	0.422***	0.711**	0.326	-0.912**	-0.453	0.425	-0.129
	(0.142)	(0.319)	(0.438)	(0.448)	(0.704)	(0.606)	(0.238)
$\text{CapReqMeasure}_t * I_{largestbanks}$	-1.094***	-2.509*	-0.125	1.119	-0.177	-1.263	1.504*
	(0.297)	(1.336)	(0.856)	(0.679)	(0.748)	(1.136)	(0.822)
RWA Density_{t-1}	0.0273	0.00538	-0.576***	0.514***	-0.145	-0.00154	0.0577
	(0.0235)	(0.0608)	(0.106)	(0.0608)	(0.128)	(0.102)	(0.0596)
ROA_{t-1}	-0.110	-0.108	-1.082*	0.901	-1.054	0.0356	0.309
	(0.212)	(0.297)	(0.602)	(0.720)	(1.295)	(1.042)	(0.384)
Scaled Impairments_{t-1}	-0.0709	-0.271**	0.180	0.0464	0.307	-0.279	0.0454
	(0.0625)	(0.108)	(0.152)	(0.142)	(0.430)	(0.409)	(0.141)
Constant	0.00956	0.0930	0.740***	0.0935*	0.632***	0.273***	0.0717
	(0.0222)	(0.0589)	(0.0757)	(0.0523)	(0.102)	(0.0816)	(0.0551)
Methodology	FE	FE	FE	FE	FE	FE	FE
Liquidity regimes	YES	YES	YES	YES	YES	YES	YES
Observations	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Adj. R2	0.745	0.754	0.928	0.933	0.891	0.878	0.837
Adj. R2 within	0.0846	0.0548	0.255	0.294	0.0417	0.0151	0.0303
Banks	154	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 large banks adjust to decrease their liquidity transformation. The dependent variables shown in column (1) is the narrow definition of liquid assets (which comprises the most liquid assets such as cash and government bonds). Column (2) to Column (7) are respectively the six main unweighted components of the *BBLiqIndex*: 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. Large banks are defined as banks that are always among the 10 largest banks throughout the whole time span of our sample. We do not include total assets in the control variables to avoid possible collinearity with our dummy variables capturing large banks.

banks. This is shown in the interaction term of the capital requirement and the big bank dummy. Consistent with previous results, most coefficients of the interaction term are of the opposite sign to that for small banks. However, the total effect of capital on liquidity transformation is only significant in Columns (1) and (7). The results suggests that after an increase in capital requirements, large banks seem to reduce their most liquid assets and increase their off-balance sheet exposure, while small banks increase the first, but do not change the second.

3.4.5 Robustness

Our main results hold with alternative versions of the liquidity index and using pooled OLS. This is shown in Table 8. 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 (since 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), 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.

4 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 link between banks' capital and their liquidity holdings as well as their overall degree of liquidity transfor-

Table 8: Robustness

	Dependent variable: Liquidity transformation - *BBLiqIndex*		
	OLS	Excluding capital	Excluding off-balance sheet
	(1)	(2)	(3)
Independent variables			
CapReqMeasure_t	-1.215***	-0.915**	-0.881**
	(0.363)	(0.433)	(0.362)
RWA Density_{t-1}	0.396***	0.270***	0.224***
	(0.0405)	(0.0504)	(0.0563)
ROA_{t-1}	-1.492	0.842	-0.179
	(0.992)	(0.682)	(0.295)
$\text{Scaled Impairments}_{t-1}$	0.208	0.161	0.236**
	(0.280)	(0.119)	(0.111)
$\ln(\text{Total Assets})_{t-1}$	-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.

mation. We find that the relationship between bank capital and asset liquidity is of an inverted U-shape while with respect to liquidity transformation, an increase in bank capital will induce banks to reduce their liquidity transformation. Our empirical results support these predictions. When examining the mechanics behind these adjustments, 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. However, we do find a statistically significant difference in the behaviour of small versus largest banks.

In general, our results suggest that capital and liquidity requirements are, at least to some extent, substitute. The empirical findings on the difference between behaviours of small banks and large banks are interesting insight for the debate on the proportionality of prudential regulations.

A Appendix

A.1 Proof of Lemma 1

From Equation (7), using implicit differentiation rule, we have:

$$\frac{\partial \overline{\delta}(k,c)}{\partial c} = \frac{1 - p^e + (1-c)\frac{\partial p^e}{\partial c}}{(1-k) - (1-c)\frac{\partial p^e}{\partial \delta}} \tag{18}$$

and

$$\frac{\partial \overline{\delta}(k,c)}{\partial k} = \frac{\delta + (1-c)\frac{\partial p^e}{\partial k}}{1 - k - (1-c)\frac{\partial p^e}{\partial \delta}} \tag{19}$$

Hence, to determine the sign of the impact of k and c on $\overline{\delta}$, we have to determine how $p^e(\delta, k, c)$ changes with k, c and δ. Using Equation (6) that defines $p^e(\delta, k, c)$, we get:

$$\frac{\partial p^e}{\partial \delta} = \begin{cases} \frac{(1-k)\frac{G'(q)}{G(q)}}{1+\frac{G'(q)}{G(q)}q} & \text{if} \quad q = \frac{\delta(1-k)-c}{p^e} \\ 0 & \text{if} \quad q = 1-c \end{cases}$$

Given that $G(q)$ satisfies the third condition in Assumption 1, we obtain:

$$\frac{\partial p^e}{\partial \delta} \leq 0 \tag{20}$$

Similarly, we have

$$\frac{\partial p^e}{\partial k} = \begin{cases} \frac{-G'(q)\frac{\delta}{p^e}}{1+\frac{G'(q)}{G(q)}q} & \text{if} \quad q = \frac{\delta(1-k)-c}{p^e} \\ 0 & \text{if} \quad q = 1-c \end{cases}$$

and

$$\frac{\partial p^e}{\partial c} = \begin{cases} \frac{-G'(q)\frac{1}{p^e}}{1+\frac{G'(q)}{G(q)}q} & \text{if} \quad q = \frac{\delta(1-k)-c}{p^e} \\ \frac{-G'(q)}{1+\frac{G'(q)}{G(q)}q} & \text{if} \quad q = 1-c \end{cases}$$

which, together with the third condition in Assumption 1, implies that

$$\frac{\partial p^e}{\partial k} \geq 0 \quad \textit{and} \quad \frac{\partial p^e}{\partial c} > 0 \tag{21}$$

Using Results (20) and (21) and the fact that $p^e < 1$, we could see from Equation (18) and (19) that

$$\frac{\partial\overline{\delta}(k,c)}{\partial c} > 0 \quad and \quad \frac{\partial\overline{\delta}(k,c)}{\partial k} > 0$$

A.2 Proof of Corollary 1

Using implicit differentiation rule, we obtain from Equation (10):

$$\frac{dc^*}{dk} = -\frac{-\frac{\partial^2 A(k,c)}{\partial c \partial k}}{-\frac{\partial^2 A(k,c)}{\partial c^2}} = \frac{\frac{\partial^2 A(k,c)}{\partial c \partial k}}{\frac{\partial^2 \Pi^B}{\partial c^2}} \tag{22}$$

Since $\frac{\partial^2 \Pi^B}{\partial c^2} \leq 0$, the sign of $\frac{dc^*}{dk}$ will be the same as the sign of $-\frac{\partial^2 A(k,c)}{\partial c \partial k}$

A.3 Derivation of the impact of capital on the failure threshold

In the equilibrium, Equation 7 can be rewritten as follows:

$$\frac{\overline{\delta}(1-k) - c(k)}{[1-c(k)]\, p^e(\overline{\delta}, k, c(k))} = 1 \tag{23}$$

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

$$\overline{\delta}(1-k) - c(k) - [1-c(k)]\, p^e(\overline{\delta}, k, c(k)) = 0 \tag{24}$$

Now using the implicit differentiation we get:

$$\frac{d\overline{\delta}}{dk} = -\frac{-\overline{\delta} - \frac{\partial c}{\partial k} p^e + \frac{\partial c}{\partial k} - (1-c(k))\frac{\partial p^e}{\partial k}}{1 - k - (1-c(k))\frac{\partial p^e}{\partial \delta}} \tag{25}$$

After some rearrangement, we have

$$\frac{d\overline{\delta}}{dk} = \frac{\overline{\delta} + (1-c)\frac{\partial p^e}{\partial k} + (1-p^e)\frac{\partial c}{\partial k}}{1 - k - (1-c)\frac{\partial p^e}{\partial \delta}} \tag{26}$$

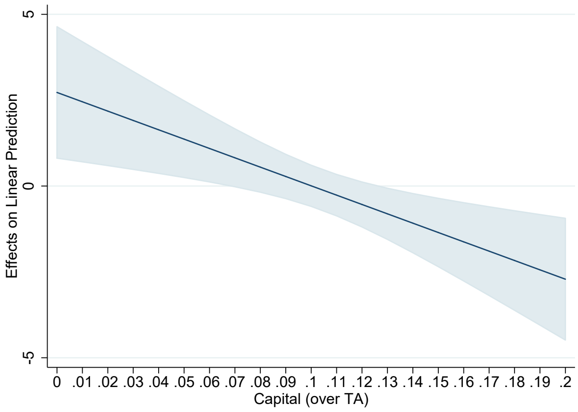
A.4 Past liquidity regimes in the UK

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.

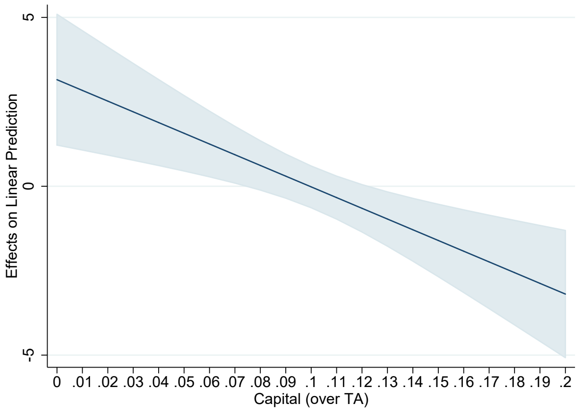
Time period	**Pre-2010**			**Post-2010**
Regime name	Sterling stock regime (started in 1996)	Mismatch liquidity regime	Building society regime	Individual Liquidity Guidance (ILG)
Coverage	Major sterling clearing banks	Other banks	Building societies	All banks in principle, though waivers and modifications 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.5 Total effect of capital on liquid assets

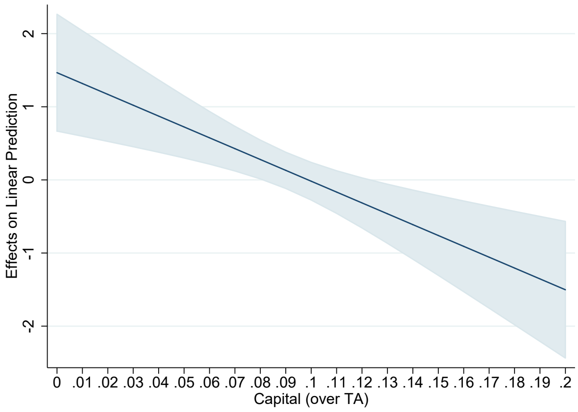
We plot below the first derivative of the Right Hand Side of Equation (16) (i.e. $\beta_2 + \beta_3\ CapReqMeasure_{i,t}$). It allows us to identify the turning point after which the total effect of capital ratio on asset liquidity turns negative. We find that, in all three specifications, this point is situated around a leverage ratio of 10%.



(a) Liquid assets (BB)



(b) Broad liquid assets



(c) Narrow liquid assets

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