Bank capital and liquidity transformation *

Jonathan Acosta Smith†
Bank of England

Guillaume Arnould‡
Bank of England

Kristoffer Milonas§
Moody’s Analytics

Quynh-Anh Vo¶
Bank of England

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Abstract

We study the interaction between bank capital and liquidity transformation from both theoretical and empirical perspectives. We use a confidential Bank of England dataset to identify how bank-specific changes in capital requirements influence banks’ liquidity-transformation decisions. We find that banks engage in less liquidity transformation when they have higher capital requirements. This finding suggests that capital and liquidity requirements are at least to some extent substitutes. By establishing a robust causal relationship, our results can help guide the optimal calibration of capital and liquidity requirements.

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†Jonathan.Smith@bankofengland.co.uk
‡Guillaume.Arnould@bankofengland.co.uk
§Kristoffer.Milonas@moodyys.com
¶Quynh-Anh.Vo@bankofengland.co.uk
1 Introduction

This paper aims to study how bank capital affects liquidity transformation both theoretically and empirically.

Theoretically, we develop a model where banks may invest some of their funds into liquid assets in order to be able to deal with deposits withdrawal. We then examine how banks’ optimal liquidity holdings are affected by their capital ratio. We found that banks’ capital ratio has two main effects on the banks’ choice of liquidity holdings. First, higher capital ratio means that banks have more stable liability structures, which in turn implies lower need for liquidity holdings. Second, higher capital ratio leads to higher cost of early liquidation due to insufficient liquidity holdings (i.e. "skin in the game" effect), which induces banks to hold more liquidity. The overall effect depends on the level of capital ratio, the profitability of long-term assets and the distribution of the early withdrawal.

Empirically we use a confidential dataset that covers the UK’s unique capital requirements regime, where firm-level regulatory add-ons were set in an arguably exogenous fashion. This exogeneity allows us to establish the causality of the impact of banks’ capital ratio on their choice of liquidity risk. By robustly measuring the empirical magnitude of the interaction, our results could be useful for understanding the interaction between capital and liquidity regulation introduced after the crisis, and thereby guiding the optimal future calibration of such requirements. Understanding such interactions is a key priority for policy makers\(^1\). In particular, if better-capitalised banks engage in less maturity transformation, relaxing liquidity and funding requirements may be warranted for a subset of banks or more broadly, following the stricter capital requirements in Basel III (cf. van den Heuvel, 2016).

The paper is structured as follows. Section 2 reviews the academic literature. Section 3 sets out the theoretical model, and Section 4 explains the empirical approach and presents our results.

2 Related Literature

This section reviews first the theoretical and then the empirical literature related to our work.

2.1 Theoretical literature

The theoretical literature has identified two channels through which bank capital may impact liquidity risk-taking. The first is the ‘loss-absorbing channel’: since capital acts as a loss absorbing buffer, banks with higher capital ratios should be less vulnerable to runs (from both deposits and short-term wholesale funding). This lower run-risk allows highly capitalised banks to take on greater liquidity risk. Repullo (2004), Allen and Gale (2004), among others, analyse this role of bank capital in the context of credit risk. Schanz (2013) formalises this argument in the context of liquidity risk. The model hypothesises that better capitalised banks are able to meet temporary funding stress more easily as these banks can raise the rate they pay to creditors while still remaining solvent. Schanz therefore argues that banks will, as a result, reduce their holdings of liquid assets as there is less need to self-insure.

The second channel is the ‘incentive channel’. This works through the incentives a change in capital has on bank liquidity risk-taking. Gomez and Vo (2016) analyse a model where banks control their liquidity risk by managing their liquid asset positions. They find that banks choose to prudently manage their liquidity risk (i.e. hold a sufficient buffer of liquid assets to be insured against liquidity risk) only when their leverage is low. The intuition is as follows: the lower the bank’s capital ratio, the higher the bank’s exposure to roll-over risk (i.e. liquidity risk). To insure against this risk, the bank needs to hold a large amount of liquid assets, which is costly since liquid assets are generally less profitable than illiquid ones. As a result, a bank with little capital will find it relatively expensive to insure against this risk, which incentivises the bank to take on greater liquidity risk\(^2\).

\(^2\)Indeed, the model predicts that below some threshold value, the cost of insurance can be larger than the cost of default meaning the bank takes maximum liquidity risk - i.e. holds no liquid assets. For
2.2 Empirical literature

Our paper relates to two empirical literatures: first, on capital-liquidity interactions; and second, using specific features of the UK capital regime to establish causality.

2.2.1 Capital-liquidity interactions

The empirical literature on the relationship between capital and liquidity is fairly limited. Most prominently, Berger and Bouwman (2009) document that among US banks, more capital is associated with more liquidity creation (ie more liquidity transformation) for large banks, while the relationship is negative for smaller banks. They interpret these patterns by noting that the theoretical predictions are differently relevant for different types of banks. In particular, monitoring theories a la Diamond and Rajan (2000, 2001) are more relevant to the borrowers of small banks, and the “crowding out” theories are also more relevant for them. In contrast, the “risk absorption” hypothesis may be more relevant for large banks, who are subject to closer scrutiny from the market and regulators\(^3\). Berger and Bouwman acknowledge however that this study is mainly correlational, although they do attempt to add some robustness via instrumental variables\(^4\).

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


\(^3\)Similarly, Fungacova, Weill and Zhou (2010) document that when bank funding becomes less fragile the effect of capital on liquidity creation is reduced, using the introduction of deposit insurance in Russia as a natural experiment.

\(^4\)As is often the case, the validity conditions for the instruments are not obviously satisfied; hence, complementary evidence using an alternative identification strategy is of clear necessity. In particular, the relevance of the tax rate 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 questionable since the share of seniors might also affect banks’ investment opportunities, which might affect their liquidity creation choices.
find negative relations between capital and liquidity creation using simultaneous equations models for international and Eurozone banks, respectively. More correlational evidence is presented by Bonner and Hilbers (2015), suggesting that there was negative relation between capital and liquid asset holdings among international banks.

Berger et al. (2016) find that official capital support actions are associated with less liquidity creation among German banks, but do not interpret their results as the causal result of increased capital levels.

These studies focus on banks’ capital and liquidity levels measured in isolation. Pierret (2015) empirically documents a systemic solvency-liquidity nexus, where banks whose exposures to systemic risks makes their solvency more fragile lost their access to short-term funding markets in the crisis.

A final stream of literature instead uses variation in liquidity requirements. De Haan & van Den End (2013) find that more solvent banks hold less liquid assets against their stock of liquid (i.e. runnable) liabilities, using a sample of Dutch banks. Banerjee and Mio (2017) find no effect of changes in firm-level individual liquidity requirements on capital structure choice, but note that their setting is not ideal for that question. Empirically, they exploit the non-simultaneous introduction of the individual liquidity guidance (ILG) regime, and seek to econometrically control for the non-random selection into treatment.

2.2.2 Research using the UK capital regime to establish causality

The UK regime of individual capital requirements has been used mainly to study the effect of capital requirements on lending. Under this regime, the prudential regulator set capital requirements additional to those in international standards, which varied between

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5Horvath, Seidler and Weill (2016) also show that capital reduces liquidity creation in a Granger-causal sense among Czech banks.

6In addition, Khan, Schuele and Wu (2016) suggest that higher capital buffers mitigates the effect of funding liquidity (measured as deposits to total assets) on risk taking, using spreads on non-financial commercial paper as an instrument for funding liquidity (following Acharya and Naqvi, 2012). Finally, Sorokina et al. (2017) document that the correlation between US banks’ liquidity and capital changes sign in recessions.

7A conceptually similar strategy using conduct-related provisions is used by Tracey et al. (2016). Compared to the individual capital requirements; this approach would cover a shorter and later time period (the regime inducing the provisions was started in 2010).
banks and over time. Broad features of the regime are discussed in e.g. De-Ramon, Francis and Milonas (2017), and Bahaj and Malherbe (2016).

Key benefits of the regime for the purpose of causal identification include that it was:

- Arguably exogenous with respect to credit risk and loan growth. The FSA reviewed firm risk management processes, systems and controls (see e.g., Aiyar, et al., 2014a,b,c; Bahaj and Malherbe, 2016; De Marco and Wieladek, 2016; Turner, 2009). Importantly, we have no evidence that liquidity risk was considered in setting these requirements.  

- Firm-specific - changed at different points in time for different banks (sometimes between regular reporting periods).

- Often binding on banks’ behaviour: Aiyar et al. (2014c) consider the extent to which capital requirements were binding on bank behaviour, based on the co-movements between weighted capital ratios and weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements that they maintain. For all four groups of banks, the variation in minimum capital requirements was associated with substantial co-movement between minimum requirements and actual capital ratios, confirming the conclusions of Alfon et al (2004) and Francis and Osborne (2012) that capital ratio requirements were binding on banks’ choices of capital ratios for UK banks during this sample period. In contrast, liquidity requirements were set in a fairly mechanical manner and typically not binding for large firms (Chaplin et al., 2000)\(^\text{10}\).

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8FSA (2011) discuss how liquidity was generally given low priority in its supervisory work before the crisis. A potential complication could be that e.g. the quality of the firm’s internal governance could both have an effect on the individual capital requirements and an independent effect on maturity transformation that does not run through capital requirements (cf. Diaz Huang, 2017). A potential way to address such problems could be study whether there are pre-trends.

9To be precise, note that the HBRD does not include the exact date when capital requirements were changed, changes are by quarter. Nevertheless, that the exact date could be extracted from the underlying data sources if deemed necessary.

10See also FSA (2011) for shortcomings of earlier domestic UK liquidity regimes.
3 The Model

3.1 Environment

We consider an economy that lasts for three dates $t = 0, 1, 2$. There is a bank with balance sheet of size normalized to 1. We assume that the bank is funded at date 0 by equity ($k$) and retail deposits ($1 - k$). The bank has access to two investment opportunities. The first is a liquid asset that has a net return of zero. The second is a constant returns to scale project, which we refer to as long-term (or illiquid) asset. This asset requires a start-up investment at date $t = 0$ and generates a per unit cash flow $R > 1^{12}$ at date $t = 2$.

Depositors can withdraw money at date 1. Denote by $\delta \in [0, 1]$ the fraction of depositors who will withdraw at date 1. $\delta$ is realised at date 1 and not known at date 0. At date 0, it is known that $\delta$ is distributed according to some distribution $F(\cdot)$. If the bank’s liquid asset holdings at date 1 are insufficient to cover the withdrawal, the bank will need to sell some (or all) of its long-term assets. We assume that due to some kind of asset specificity, potential buyers are less efficient than the bank in managing the long-term assets, which implies that these assets will be sold at a unit price lower than their fundamental value $R$. We further assume that the price discount is increasing with the quantity of assets sold. This could be justified by the fact that the technology used by potential buyers to manage the long-term assets has decreasing returns to scale. Denote by $G(\cdot)$ this technology.

At date 0, the bank has to decide how much to invest in the liquid and long-term illiquid assets. Denote by $c$ its liquid asset holdings. Hence $1 - c$ will be invested in the long-term assets. The timing of the model is summarised in Figure 2b.

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11 Note that since we normalise the size to 1, $k$ could also be interpreted as the bank’s capital ratio.
12 The assumption of deterministic cash flow of long-term assets allows us to focus on bank’s choice of liquidity risk in abstraction of credit risk.
3.2 Analysis

We now analyse the bank’s optimal investment decision at date 0. Our main objective is to study how much liquid assets the bank will hold on its balance sheet and how this decision is affected by the bank’s capital ratio $k$. We will proceed in two steps. First we determine the unit price of long-term assets at date 1. Then, we examine the bank’s optimal liquidity holdings at date 0.

- **Price equilibrium**

At date 1, given $c$, the bank will have to sell long-term assets when $\delta(1 - k) > c$. In that case, the fraction $\beta$ of long-term assets being sold is determined as follows:

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

where $p$ is the unit price of long-term assets that is determined as follows:

$$p = G[\beta(1 - c)] = G[\frac{\delta(1 - k) - c}{p}]$$

Figure 1: The timeline
Denote by $p^e(\delta, k, c)$ the equilibrium price determined by (1). Hence, given $k$ and $c$, the fraction of long-term assets that need to be sold is as follows:

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

Note that if $\beta$ is greater than or equal to 1, the bank has to sell all of its long-term assets and will be closed. This situation happens when the fraction $\delta$ of depositors who withdraw at date 1 is greater than some threshold $\delta(k, c)$ that is defined implicitly by the following equation:

$$\frac{\delta(1 - k) - c}{(1 - c)p^e(\delta, k, c)} = 1$$  \hspace{1cm} (3)

Hence, as of date 0, the bank’s probability of being illiquid is:

$$P(\delta \geq \delta(k, c)) = 1 - F(\delta(k, c)).$$

which is the measure of liquidity risk in our model.

• **Bank’s optimal liquidity holdings**

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

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

$$- \int_{\delta(k,c)}^{1} [R - 1 + k - c(R - 1)] f(\delta)d\delta$$  \hspace{1cm} (4)

Hence, basically, the bank’s expected profit is equal to the expected profit, represented by the first term in the bracket of the right hand side (RHS) of Expression (4), if there is no potential liquidity problem at date 1 deducted by two terms that represent the expected losses the bank will incur if its ex-ante liquidity holdings are not sufficient to cover early withdrawals. Precisely, the second term of the RHS of Expression (4) stands for the expected losses when the bank has to sell a fraction of its long-term assets at a fire
sale price (i.e. at price lower than its fundamental value). The third term of the RHS of Expression (4) corresponds to the expected losses due to the fact that the bank is closed early since it cannot raise enough liquidity even when it sells all of its long-term assets. It is easily to see that these two terms are decreasing with the bank’s ex-ante liquidity holdings $c$.

Expression (4) also makes clear the trade-off driving the bank’s liquidity holding decision. The cost of holding liquidity is the foregone return of the long-term assets, which is represented by the term $(-c(R - 1))$ in the bracket of the RHS of Expression (4). The benefit of holding liquidity lies in the reduction of the expected losses the bank has to incur.

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

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

(5)

where

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

and

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

This is a useful way to look at the optimality condition because it equates the expected marginal benefit of holding liquidity and its expected marginal cost. After some algebras, we could rewrite FOC (5) as follows:

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

(6)

Although the marginal cost of liquidity holdings does not depend on the bank’s capital
ratio, the marginal benefits do. Basically, bank’s capital ratio has two main effects on the bank’s choice of liquidity holdings. First, higher capital ratio means that the bank has more stable liability structures, which in turn implies lower need for liquidity holdings. Second, higher capital ratio leads to higher cost of early liquidation due to insufficient liquidity holdings (i.e. "skin in the game" effect), which induces banks to hold more liquidity. The overall effect depends on the level of capital ratio, the profitability of long-term assets and the distribution of $\delta$.

• Numerical example

Unfortunately, FOC (5) can generally not be solved for $c$ in closed form. We therefore consider here a numerical example in which $\delta$ is uniformly distributed and the technology $G(.)$ of potential buyers takes the form as follows:

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

Figures 2a and 2b shows respectively the bank’s optimal liquidity holdings and its probability of surviving at date 1 as a function of its capital ratio when $R = 1.1$.

Hence, in this numerical example, higher capital ratio induces the bank to choose less liquidity risk since its probability of surviving the liquidity shock is increasing with $k$. 
We also construct a theoretical counterpart of our empirical liquidity creation measure and Figure 3 shows how this measure varies with the capital ratio when $R = 1.1$.

4 Empirical strategy and results

4.1 Data

We use the historical regulatory database for the UK banking sector described in De-Ramon, Francis and Milonas (2017). The data is a confidential Bank of England database, at semi-annual frequency. It covers a period from 1989H2 to 2013H2 and is unbalanced, given that some firms go bankrupt, other are bought and new entrants join the market (either new banks created or foreign banks opening a subsidiary in the UK). It covers actual and required levels of capital as well as other measures of bank balance sheet.

We include all banks operating in the UK at a consolidated level (we don’t include branches) in the sample\textsuperscript{13}. Because we restrict our sample to actual changes in capital requirement, in total we have an unbalanced panel of 388 observations for 67 banks. Table 1 shows summary statistics of banks in our dataset.

Our sample encompasses several type of firms with different balance sheets’ compositi-
Table 1: Summary statistics (percentages unless noted otherwise)

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>sd</th>
<th>p10</th>
<th>median</th>
<th>p90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required capital to RWA*</td>
<td>12.1</td>
<td>4</td>
<td>8.8</td>
<td>11.2</td>
<td>16.9</td>
</tr>
<tr>
<td>Total capital to RWA</td>
<td>23.7</td>
<td>22.2</td>
<td>11.4</td>
<td>17</td>
<td>41.7</td>
</tr>
<tr>
<td>Deposits (non-financial) to GTA**</td>
<td>41.1</td>
<td>27.1</td>
<td>2.1</td>
<td>40.2</td>
<td>79.5</td>
</tr>
<tr>
<td>Mortgage loans to GTA</td>
<td>13.4</td>
<td>19.8</td>
<td>0</td>
<td>4.6</td>
<td>49.7</td>
</tr>
<tr>
<td>Liquid assets (broad) to GTA</td>
<td>13.3</td>
<td>11.9</td>
<td>0.3</td>
<td>11.4</td>
<td>26</td>
</tr>
<tr>
<td>Liabilities other than deposits or capital to GTA</td>
<td>36</td>
<td>26.4</td>
<td>4.8</td>
<td>31.4</td>
<td>75.8</td>
</tr>
<tr>
<td>Off-BS guarantees to GTA</td>
<td>11.5</td>
<td>12.3</td>
<td>0.2</td>
<td>7.2</td>
<td>26.4</td>
</tr>
<tr>
<td>Total assets (m)</td>
<td>111,059</td>
<td>308,936</td>
<td>284</td>
<td>5,597</td>
<td>285,137</td>
</tr>
</tbody>
</table>

Notes: RWA = risk-weighted assets and GTA = gross total assets = total assets + total off-BS guarantees

4.1.1 Individual capital guidance

Individual capital guidance that were set by the FSA, were arguably exogenous with respect to credit risk, loan growth and business models. Individual capital guidances were mainly based on supervisory judgements on organisational structure, systems and reporting procedures, quality of management (Turner, 2009 and Francis and Osborne, 2012). Importantly, we have no evidence that liquidity risk was considered in setting these requirements.\(^\text{14}\) Individual capital guidance changed at different points in time for different banks (sometimes between regular reporting periods), changes are by quarter and are assign to the corresponding semester. There is heightened activity in the late 90s and early 2000s (Figure 4) which largely represents efforts to improve consistency between different types of firms following the creation of the FSA in 1997 (Bahaj and Malherbe, 2016, De-Ramon et al., 2017). Interestingly, the number of capital increases and capital decreases are rather similar, which allow us to analyse the differential effect. Individual capital guidance were set individually for the banking book and the trading book. We slightly diverge from Bahaj and Malherbe (2016) who look at the aggregate individual capital guidance, we track every single changes for both banking and trading book with

\(^\text{14}\) FSA (2011) discuss how liquidity was generally given low priority in its supervisory work before the crisis.
a minimum change of 0.5%. We can then track more accurately each single changes in the individual capital requirements set by the supervisors. Aiyar et al. (2014c) consider the extent to which capital requirements were binding on bank behaviour, based on the co-movements between weighted capital ratios and weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements that they maintain. For all four groups of banks, the variation in minimum capital requirements was associated with substantial co-movement between minimum requirements and actual capital ratios, confirming the conclusions of Alfon et al (2004) and Francis and Osborne (2012) that capital ratio requirements were very often binding on banks’ choices of capital ratios for UK banks during this sample period. We find too a significant positive correlation between total capital and the individual capital guidance (see Figure 5).
4.1.2 Liquidity regimes

In contrast to capital requirements, liquidity requirements were set in a fairly mechanical manner and typically not binding for large firms (Chaplin et al., 2000)\(^\text{15}\). Nonetheless, we build dummies for past liquidity regimes to control for any impact on firms’ liquidity decisions. Until 2010, there was three liquidity regimes: the Sterling Stock for the 17 largest firms, the Building society regime for building societies and the Mismatch regime for all the other firms, including subsidiaries of foreign banks. After 2010, the FSA replaced the three liquidity regimes with a single one, covering all banks, with some exemptions (Banerjee and Mio, 2017): the Individual Liquid Guidance.

The Sterling Stock liquidity regime was introduced in 1996 and applied to the 17 largest UK banks on a consolidated basis. The objective of the regime was to ensure that firms had enough highly liquid assets to meet its outflows for the first week of a liquidity crisis, without recourse to the market for renewed wholesale funding, to allow the authorities time to explore options for an orderly resolution. The Mismatch regime

\(^{15}\)See also FSA (2011) for shortcomings of earlier domestic UK liquidity regimes.
applied to all non-Sterling Stock banks, which comprises the majority of UK banks. The regime aimed to ensure that a bank had sufficient maturing and readily marketable assets to cover maturing liabilities, through limiting the mismatch between the inflows and outflows for different maturity. The Building society regime is much simpler that the two previous regimes and reflects the simpler business model (residential mortgage lending primarily funded out of retail savings). It set a limit on short-term liability building societies can have and an amount of liquid assets. The regulator also set out a matrix of asset suitable to be held as liquidity. Though, the rules did not set a hard minimum for total liquidity but a range. In practice, building societies natural caution means that most target to hold liquidity well above their policy or regulatory minimum.

In 2010, the FSA introduced the Individual Liquidity Guidance. Only subsidiaries of foreign banks for which home supervisor’s liquidity regime was deemed broadly equivalent and the FSA was granted the ability to monitor liquidity of the consolidated group, were exempted (FSA, 2009). There is no indication that ILG exemption were motivated by the liquidity positions of the concerned banks (Banerjee and Mio, 2017). Under the new liquidity regime banks were required to hold a stock of liquid assets sufficient to cover a proportion of the net outflows that would occur in a severe two-week firm-specific stress combined with a milder three-month market-wide stress. This is conceptually similar to the LCR, but the minimum is not 100%. An important point is that when the FSA introduced the new liquidity regime, it took the decision not to tighten quantitative standards given that firms were still experiencing difficulties after the financial crisis (FSA, 2009).

4.1.3 Liquidity measures

Our main liquidity measure is based on the liquidity creation measure used by Berger and Bouwman (2009). We diverge slightly given that we scale the measure to make it comparable between banks. In addition, we make some changes to the treatment of off-balance-sheet commitments and guarantees. These adjustments are motivated by data
limitations and are unlikely to have material impacts.\textsuperscript{16} We build alternative versions of the measure build by Berger and Bouwman (2009) to test the robustness of our results and build a proxy of the NSFR.

Our main measure is:

\[ liq.\text{creation} = \frac{\sum_i \text{notionalvalue}_i \times \text{weight}_i}{\text{assets} + \text{offBScommitments\&guarantees}} \]

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

The liquidity index based on Berger and Bouwman (2009) is based on the ease, cost and time for banks to meet creditors’ demand (liability side), and the ease, cost of time to obtain liquid funds (asset side). For example, wholesale funding is considered as a liquid liability, given that creditors can choose not to roll over without much costs and time. Alternatively, capital is an illiquid liability; it is nearly impossible for a shareholder to ask the bank to buy back its shares, and retained earnings belong directly to the bank. Loans are considered illiquid, given that they are difficult to sell on a secondary market, while gilts are liquid assets, that have a large and liquid second market.

Maximum liquidity is created when illiquid assets, loans for example (weight of 0.5), are transformed into liquid liabilities, deposits for example (weight of 0.5), creating $1$ of liquidity, which gives 0.5 with our liquidity index given that we scale by total assets.

This measure is a liquidity transformation measure. We argue that liquidity transformation is positively correlated to liquidity risk given that a higher mismatch between assets and liabilities generates higher potential losses.

In our main measure, we consider deposits as a liquid liability (as in Berger and Bouwman, 2009), hence expose to a run. If the recent crisis has shown that this characteristic of deposit was not completely removed by the introduction of a deposit insurance (see the run on Northern Rock in 2007, or the situation in Greece since 2015), deposits are stripped of them. Table 6.1 in the appendix shows that our main results hold.

\textsuperscript{16}We control for the treatment of off-balance sheet commitments with a variation of our main measure.
Table 2: Liquidity index

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities plus equity</th>
<th>Off-balance sheet commitments and guarantees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illiquid assets (w = 0.5)</td>
<td>Semi-liquid liabilities (w = 0)</td>
<td>All off-balance sheet commitments and guarantees (w=0.5)</td>
</tr>
<tr>
<td>Semi-liquid assets (w = 0)</td>
<td>Illiquid liabilities (w = -0.5)</td>
<td></td>
</tr>
<tr>
<td>Loans except residential mortgages</td>
<td>All capital</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Liquid assets includes high quality liquid assets (cash and balances at central banks, gilts, treasury bills and other highly liquid bills) as well as credit to other financial institutions, debt securities, and equity shares. All off-balance sheet commitments and guarantees includes direct credit substitutes, transaction and trade-related contingents, sale and repurchase agreements, asset sales with recourse, forward asset purchases, forward deposits placed, uncalled party-paid shares and securities, NIFs and RUFs, endorsements of bills, and other commitments.

usually rather sticky and stable. We build an alternative measure to test the alternative, where we consider deposits as illiquid liabilities.

We also build a liquidity measure based on the NSFR following BCBS (2014). This measure is a ratio of available stable funding over required stable funding, that measures the maturity mismatch of banks. Conceptually, it is close to the measure of Berger and Bouwman (2009), given that it compares stable funding (or illiquid liabilities) to illiquid assets (Table 3). An important difference lies in the treatment of deposits, which are considered as liquid in Berger and Bouwman (2009), while they are considered as a stable source of funding in the NSFR.
Table 3: NSFR index

<table>
<thead>
<tr>
<th>Available stable funding</th>
<th>Liabilities</th>
<th>weight</th>
<th>Required stable funding</th>
<th>Assets</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>1</td>
<td>Other assets</td>
<td>1</td>
<td>Mortgages and other loans</td>
<td>0.85</td>
</tr>
<tr>
<td>Customers deposits</td>
<td>1</td>
<td>Mortgages and other loans</td>
<td>0</td>
<td>Trading book</td>
<td>0.5</td>
</tr>
<tr>
<td>Other liabilities</td>
<td>0</td>
<td>Other commitments</td>
<td>0.05</td>
<td>Liquid assets</td>
<td>0</td>
</tr>
</tbody>
</table>

The NSFR index is calculated as follows:

\[
NSFR = \frac{\sum_i available\ funding_i \times weight_i}{\sum_j required\ funding_j \times weight_j}
\]

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

4.2 Econometric methodology

4.2.1 Specification

Using firm-level data, our main regression is:

\[
LiqMeasure_{i,t} = \beta_1 + \beta_2 CapReqMeasure_{i,t} + \beta_3 controls_{i,t-1} + u_i + time_t + \epsilon_{i,t},
\]

where \(i\) represents a bank and \(t\) the time-period. \(LiqMeasure\) is one of our measure of liquidity risk and \(CapReqMeasure\) a measure of capital requirements (e.g. individual capital guidance over regulatory risk-weighted assets). We add a set of bank level variables (controls) to control for banks’ risk profile: return on assets, non-performing loans over total loans and impairments over total loans\(^{17}\); and the liquidity regime they are subjected to (see Section 4.1.2). Controls are lagged by one period to reduce potential endogeneity problems.

\(^{17}\) The three variables are not strongly correlated, thus the inclusion of the three should not create any endogeneity problems.
tial endogeneity problems. We estimate this model using fixed effect at the bank level \((u)\), to account for average differences over time across banks that are not captured by other exogenous variables and to reduce correlation across error terms, and time fixed effect \((time)\), to control for average differences in our liquidity measures across years. All regressions are estimated using robust standard errors, clustered by bank, to control for heteroskedasticity. Finally, \(\epsilon\) is an error term (which might be non-independent between observations).

Additionally, to explore the drivers of the relation between capital and liquidity using a variable \(Z\), we decompose the coefficient \(\beta_2\):

\[
\beta_2 = \beta_3 + \beta_4 Z_{i,t}
\]

In total, we estimate the following equation:

\[
LiqMeasure_{i,t} = \beta_1 + (\beta_3 + \beta_4 Z_{i,t}) \times CapReqMeasure_{i,t} + \beta_5 Z_{i,t} + \beta_6 controls_{i,t-1} + u_i + time_t + \epsilon_{i,t},
\]

This equation investigates if the effect of capital on our liquidity measures vary across the variable \(Z\). This variable can be the size of the bank, its capital buffer or the direction of change of capital requirements (namely increases versus decreases). In the last case we don’t introduce the stand-alone variable \(Z_{i,t}\) given that it does not carry any economic meaning.

4.2.2 Identification

In practice, banks’ capital and banks’ liquidity are to some extent jointly determined. To mitigate this potential endogeneity problem and establish causality, we exploit a specific feature of UK regulatory regime. That is the fact that the supervisor could impose a requirement in excess of the 8% minimum. A breach of this requirement would then trigger supervisory intervention. Moreover, the supervisor had discretion and could
set these requirements at different levels for different banks and could also change them overtime. Of course, changes in a bank’s individual capital requirements were not literally random. However, the key condition for a causal interpretation to be valid in our analysis is that changes in capital requirements imposed by regulators are not driven by changes in banks’ liquidity risk. There are indeed many reasons to believe that liquidity risk was not taken into account in setting these requirements in the period we study.

First, as described in Turner et al. (2009), before the financial crisis, the supervisory approach of FSA, the previous U.K. regulator, involved more focus on organisation structures, systems and reporting procedures than on overall risks in business models. The underlying reason for this focus is the philosophy that the primary responsibility for managing risks lies with the senior management and boards of individual firms who are better placed to assess business model risk than bank regulators. The latter would thus focus on making sure that appropriate systems, procedures and skilled people are in place. Second, both FSA reports on the supervision of Northern Rock and on the failure of the Royal Bank of Scotland noted that before the financial crisis, strikingly insufficient weight was given by FSA to liquidity risk in firms. Following the crisis, in response to lessons learned, FSA made reforms to increase the attention given to liquidity risk but this is more reflected in the change in liquidity regime which we control for in our regression.

4.3 Empirical results

4.3.1 Main results

We find a significant negative relation between capital requirements and liquidity creation. Given that capital changes are arguably exogenous, we argue that an increase (resp. a decrease) of capital requirements, causes a decrease (resp. an increase) of liquidity creation (Table 4). Our main result seems to confirm that on average, the skin in the game effect, trumps the risk absorbing effect. This is confirmed by our alternative measure
based on the NSFR (which has an reversed scale; a higher figure means more liquidity risk). Though, given that the $R^2$ of our measure based on the NSFR is almost half of the one of our measure based on Berger and Bouwman (2009), we focus our detailed analysis on the last one.

Table 4: Main results

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BB liquidity index</td>
<td>NSFR</td>
</tr>
<tr>
<td>Capital req.</td>
<td>-0.551*</td>
<td>4.172**</td>
</tr>
<tr>
<td></td>
<td>(0.295)</td>
<td>(1.822)</td>
</tr>
<tr>
<td>Observations</td>
<td>388</td>
<td>388</td>
</tr>
<tr>
<td>Controls</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Methodology</td>
<td>FE</td>
<td>FE</td>
</tr>
<tr>
<td>Adj. R2</td>
<td>0.754</td>
<td>0.400</td>
</tr>
<tr>
<td>Adj. R2 within</td>
<td>0.0550</td>
<td>0.0883</td>
</tr>
<tr>
<td>Banks</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>

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

We run alternative specification for robustness in Table 6.1. Our main result holds with alternative versions of liquidity index. In the first one we consider deposits as stable (ie. an illiquid liability, with a coefficient of -0.5), an in the second one we remove off-balance sheet where our classification is coarse. Additionally, we don’t find lagged relation, banks seem to adjust rapidly to any change of capital requirements. Contrary to the theoretical part, we don’t find nonlinerities.

4.3.2 Channels

We investigate the drivers of the negative coefficient we found, to uncover potential asymmetries. Is the coefficient driven by increases or decreases of capital requirements? Banks may only lower their level of liquidity risk in response to an increase of capital requirements, while they may not react to a decrease of capital requirements. This is an information that can help calibrate macroprudential requirements by informing how
banks change their level of liquidity risk taking after a change (either increase or decrease) of the macroprudential buffer.

We also investigate how does the risk appetite of banks play out? Banks’ size and capital buffer may drive their liquidity risk appetite after a change in the capital requirements. Large banks have a different business model compared to small banks and enjoy some implicit guarantee, which should affect the relation between capital and liquidity risk taking. We consider banks’ capital buffer as a proxy of their risk-taking profile, and we investigate how this affects the relation between capital and liquidity risk taking, taking into account the direction of change of capital requirements. We expect firms that are less risk adverse (i.e., with low buffers) to be those that react more to a decrease of capital requirement and increase their level of liquidity risk.

The negative coefficient we found is not driven by only one direction of change, banks react to both an increase in capital requirement by taking less liquidity risk and to a decrease in capital requirement by taking more liquidity risk (Table ??). We find a significant asymmetric reaction of firms to increases versus decreases. Firms seem to react less to a capital increase than a decrease. This can be explained by the fact that it is easier for a bank to reduce its balance sheet than expend it, or raise new capital, on short term. Overall, banks had to comply with the new requirements over a period of 7-9 months (Francis and Osborne, 2012), so we only measure their short-term reaction (our data has a semester frequency). It also means that banks tend to target the minimum capital requirement and adapt rapidly their level of liquidity risk taking (especially for a capital requirement lowering). This has policy implication, for example supervisors should pay attention to banks’ liquidity risk taking when they change macroprudential capital requirement, especially when they decrease it. Liquidity ratios appear as a good complement to capital ratios.

We investigate how the size of banks and their total capital buffer affect the relation between capital and liquidity risk taking. Large banks have a different business model compared to small banks and enjoy some implicit guarantee, which should affect the re-
Table 5: Channels

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>BB liquidity index</th>
<th>(2) BB liquidity index</th>
<th>(3) BB liquidity index</th>
<th>(4) BB liquidity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital req.</td>
<td>-0.698** (0.290)</td>
<td>-2.397* (1.350)</td>
<td>-0.579** (0.248)</td>
<td>-0.810*** (0.219)</td>
</tr>
<tr>
<td>Capital buffer</td>
<td>-0.548*** (0.166)</td>
<td>-0.978*** (0.183)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(total assets)ₜ₋₁</td>
<td>0.0188 (0.0136)</td>
<td>-0.00743 (0.0260)</td>
<td>-0.0107 (0.0119)</td>
<td>-0.0189* (0.0110)</td>
</tr>
<tr>
<td>Capital req. * Increase</td>
<td>0.154*** (0.0566)</td>
<td></td>
<td></td>
<td>0.253*** (0.0693)</td>
</tr>
<tr>
<td>Capital req. * log(total assets)ₜ₋₁</td>
<td>0.229 (0.162)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital req. * buffer</td>
<td>1.926** (0.759)</td>
<td></td>
<td>3.565*** (0.840)</td>
<td></td>
</tr>
<tr>
<td>Buffer * Increase</td>
<td></td>
<td></td>
<td>0.640*** (0.212)</td>
<td></td>
</tr>
<tr>
<td>Capital req. * buffer * Increase</td>
<td>-2.961** (1.194)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>388</td>
<td>388</td>
<td>388</td>
<td>388</td>
</tr>
<tr>
<td>Controls</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Methodology</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
</tr>
<tr>
<td>Adj. R2</td>
<td>0.757</td>
<td>0.757</td>
<td>0.794</td>
<td>0.808</td>
</tr>
<tr>
<td>Adj. R2 within</td>
<td>0.0659</td>
<td>0.0672</td>
<td>0.211</td>
<td>0.264</td>
</tr>
<tr>
<td>Banks</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

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

Notes: The buffer and the logarithm of total assets are centred to facilitate the interpretation of the coefficients of capital requirements (which represent the effect of capital on liquidity provided that Z = 0 (see equation 4.2.1)). We find that the sum of the coefficients of Capitalreq. and Capitalreq. * Increase is significantly different from zero after conducting a t-test.
lation between capital and liquidity risk taking. We consider banks’ capital buffer as a proxy of their risk taking profile, and we investigate how this affect the relation between capital and liquidity risk taking, taking into account the direction of change of capital requirements. We expect firms that are less risk adverse (i.e., with low buffers) to be those that react more to a decrease of capital requirement and increase their level of liquidity risk.

To assess how the marginal effect of size on capital, based on the coefficients of Table ??, we plot the coefficient for different values of the size in Figure 6. Smaller firms seems to react more to a change in capital requirement and adjust their level of liquidity risk taking. On the other hand, large firms’s reaction is not significantly different from zero. Contrary to Berger and Bouwman (2009), we do not find a positive coefficient for large firms. This may be due to our limited sample of large firms, as the increasing standard errors with the size suggests, given that our study is focused on the UK. If capital regulation affects positively or does not affect the level of liquidity risk taking of large firms, then liquidity regulation is central to prevent large firms from taking too much liquidity risk. On the other hand, small banks, seem to reduce their liquidity risk taking when they are ask to hold more capital, which may suggest either a redundancy between capital and liquidity regulation, or a least, a proportional approach when setting liquidity requirements for small firms.

To assess how the marginal effect of capital buffer on capital, we plot the coefficient for different values of the capital buffer in Figure 7, either in the case of an increase in capital or in the case of a decrease. The capital buffer is the difference between total capital and the individual capital guidance (see section 4.1.1), the average buffer is 14% of RWA, but this is driven by very large buffers, and the median is only 5% of RWA. We demean the buffer to facilitate the interpretation of coefficients in Table ??, For example, in the second specification, the coefficient of capital requirement is conditional on banks having buffer equal to the average. We draw the plots in Figure 7, based on the coefficient estimated in Table ?? in the third specification. We argue that the level of capital buffer
is a proxy of the risk appetite of the bank. Banks choose their level of capital buffer according to their risk appetite; firms with small buffer prefer to keep the level of capital as low as possible to leverage up as much as the regulation allow them, while firms that are more risk adverse prefer to hold more capital than regulatory minimum to protect against unexpected losses.

Firms with small buffers have to adjust quickly to a capital increase so as to comply with the regulation (Figure 7a). On the other hand, firms with large buffers have a coefficient not significantly different from zero, and do not adjust as it is not binding. In the case of capital increases, the risk appetite role of buffers is dominated by its role of leeway.

Regarding capital decreases, firms with low capital buffers react more than firms with a high buffer. Firms with low buffer, that have a high risk appetite, take use the opportunity of a capital decrease to leverage up towards more liquidity risk, on a short-term period. While firms with large buffers, tend to have a coefficient not significantly different from zero and do not react on short term.
4.3.3 How do firms adjust to capital requirement changes

In table 6, we examine how banks adjust to a change in their capital requirements. We don’t use any liquidity measure and use directly the ratio of the corresponding variable over total assets. We find that on short term, banks play on three items: liquid assets, deposits and wholesale funding. Banks play on both the asset side and liability side.

We suppose that banks adjust to an increase of capital requirements either by a rebalancing towards safer assets or by deleveraging. Given that we investigate contemporaneous relations, we suppose that banks do not have time to raise new equity. Conversely, we suppose that banks adjust to a decrease of capital requirements by leveraging-up.

We find that after an increase in capital requirements only liquid assets have a positive coefficient; semi-liquid assets and illiquid assets have a negative but insignificant coefficient. Banks deleverage, but not in a similar way, and they retain liquid assets, increasing their liquidity index as measured by Berger and Bouwman (2009). Conversely, after a decrease in capital requirements, banks leverage up but not through liquid assets.

Regarding liabilities, when banks deleverage after an increase in capital requirements, they adjust their wholesale funding and retain deposits. This is not surprising given that wholesale funding is the most liquid while deposits are quite sticky. Conversely, after a decrease of capital requirements, banks leverage up through wholesale funding and lower
The ratio of deposits over total assets. This is consistent with Hahm, Shin and Shin (2012) who find that when asset growth in banks cannot keep the pace of retail deposits, the fund their asset growth through wholesale funding.

## 5 Conclusions

We have first shown in a simple theoretical model with retail deposits withdrawals and fire-sales, that firms take less liquidity risk when their capital increases. We confirm this relation with a robust empirical assessment indicating that banks engage in less liquidity transformation when their capital requirements are higher. We find that banks adjust more their level of liquidity risk taking after a decrease in capital requirements. We show that our results are driven by small banks and banks with small buffer. Finally, we find that bank adjust their level of liquidity risk taking after a change in capital requirement by playing mainly on the less liquid assets and wholesale funding. Our results can help calibrate macroprudential requirements by informing how banks change their level of
liquidity risk taking after a change (either increase or decrease) of the macroprudential buffer.
## Appendix

### 6.1 Alternative measures

Table 7: Robustness

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB liquidity index (deposits)</td>
<td>BB liquidity index (off-balance sheet)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB liquidity index</td>
<td>BB liquidity index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB liquidity index</td>
<td>BB liquidity index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital req.</td>
<td>-1.352***</td>
<td>-0.620**</td>
<td>-0.692*</td>
<td></td>
</tr>
<tr>
<td>(0.341)</td>
<td>(0.271)</td>
<td>(0.376)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lagged capital req.,</td>
<td>1.444</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.773)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.454***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0802)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>388</td>
<td>392</td>
<td>368</td>
<td>403</td>
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<td>Controls</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Methodology</td>
<td>FE</td>
<td>FE</td>
<td>FE</td>
<td>OLS</td>
</tr>
<tr>
<td>Adj. R2</td>
<td>0.864</td>
<td>0.782</td>
<td>0.0356</td>
<td>0.190</td>
</tr>
<tr>
<td>Adj. R2 within</td>
<td>0.194</td>
<td>0.133</td>
<td>-0.0235</td>
<td></td>
</tr>
<tr>
<td>Banks</td>
<td>67</td>
<td>68</td>
<td>65</td>
<td>79</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
7 References


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