Bank of England

The impact of changes in bank capital requirements

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Akash Raja(1)

Abstract

This paper studies how banks respond to capital regulation using confidential data on bank-specific requirements in the UK. Banks do adjust their capital ratios following changes in requirements, though the pass-through is incomplete. While they lower capital ratios following a loosening of requirements, they eat into their existing capital buffers when facing tighter regulatory minima. I find that the main adjustment channels have changed since the financial crisis. Prior to the crisis, banks responded to changes in their requirements through capital accumulation and loan quantities; however, they have since then primarily altered the risk composition of assets.

Key words: Capital requirements, microprudential policy, banking, capital ratios.

JEL classification: E58, G21, G28.

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1 Introduction

The Global Financial Crisis of 2008 highlighted multiple vulnerabilities within the banking sector (Basel Committee on Banking Supervision (2009); Sironi (2018)). In order to mitigate these financial stability risks, regulators have since employed various micro- and macroprudential policy tools, one of which is bank capital requirements. These requirements, typically set as a minimum ratio of total regulatory capital to risk-weighted assets, aim to ensure that banks can withstand unexpected losses and maintain solvency in a crisis. Banks can respond to capital regulation in various ways, and the choice of response could have different macroeconomic and financial stability implications (Hanson et al. (2011)). With respect to an increase in requirements, banks can accumulate more capital, reduce total assets or shift their asset composition towards less risky assets. They could also simply maintain their capital ratios and dig into their pre-existing capital buffer provided this buffer is sufficiently large. If banks lower lending as part of their adjustment, this could adversely affect macroeconomic activity today. Instead, accumulation of more capital can improve bank resilience to future shocks, thus improving financial stability. This paper seeks to shed light on the adjustment of banks to capital regulation using confidential regulatory returns data for UK banks.

Estimating the impact of capital requirements poses empirical challenges: first, in most countries, bank capital requirements are homogeneously set across banks, often at the Basel minimum of an 8% risk-based capital ratio, which leaves little, if any, cross-sectional variation to exploit for identification. When cross-sectional variation is available, studies are sometimes constrained to look at one-off regulatory changes and to compare "treated" and "untreated" banks around singular events (e.g. Mésonnier and Monks (2015); Gropp et al. (2018)). Focusing on isolated regulatory changes can constrain the time dimension and make it difficult to study effects at longer horizons. If the policy change is particularly unique or targeted at specific banks, it may be difficult to apply these results in other settings. The second challenge is that capital requirements are not randomly allocated, making it difficult to separate the effect of a change in capital requirements from the fact that banks receiving a higher or lower requirement may be inherently different from those that do not. This selection problem can lead to endogeneity concerns if the regulatory change is not orthogonal to other drivers of the outcome.

In this paper, I address each of these empirical concerns: first, the UK is a unique setting because time- and bank-varying capital requirements known as *trigger ratios* have been in place for all regulated banks since 1989, thus providing a long time dimension simultaneously with cross-sectional variation. On the second empirical challenge, existing papers that study UK requirements reference anecdotal evidence to argue that regulators focus on non-balance sheet risks such as organizational structures and reporting procedures when setting trigger ratios (Aiyar et al. (2014)). I apply the least absolute shrinkage and selection operator (lasso) of Tibshirani (1996) to provide statistical evidence for this argument. This finding supports the identification assumption applied in the analysis that changes in bank-level capital requirements can be treated as orthogonal to bank balance sheet risks.

Using local projections à la Jordá (2005), I find that bank capital ratios do respond to a change in required ratios, although the pass-through is less than one-for-one. In my baseline specification, a 1 percentage point (pp) increase in trigger ratios causes a 0.5pp rise in actual capital ratios. Adjustments of capital ratios occur primarily through two channels: the first is capital accumulation, whereby total regulatory capital increases by around 1% in the year following a 1pp increase in capital requirements. This is predominantly driven by Tier 2 capital, which rises by 3-4% during this period. The second is a risk composition effect, whereby banks adjust their asset portfolios towards less risky assets with average risk weights, computed as the ratio of risk-weighted assets and total assets, falling by 1-1.5pps during the three years following the regulatory change. There is no significant effect on bank lending. By splitting the sample based on the direction of the regulatory change, I show that bank capital ratios respond to decreases, but not increases, in capital requirements. Instead, banks opt to dig into their existing capital buffers when faced with tighter requirements. The response of banks also appears to have changed since the financial crisis. I find that the risk composition effect is a post-crisis result. Prior to the financial crisis, adjustments occurred mainly through capital accumulation, in particular Tier 2 capital, as well as lending with the quantity of loans dropping by 5% one year after a 1pp rise in requirements.

The remainder of the paper is organized as follows: Section 2 gives an overview of the existing literature and Section 3 gives an account of the UK regulatory framework. Section 4 describes the data used in the empirical analysis with Section 5 providing descriptive statistics. Section 6 outlines the methodology and Section 7 shows the results. Robustness checks are provided in Section 8, while Section 9 concludes.

2 Literature review

The theoretical discussion gives three conditions that must be satisfied for changes in capital requirements to impact bank lending and balance sheet composition.[1] The first condition is that capital requirements should be effectively binding. This does not necessarily mean that capital ratios must exactly equal the required level at all times. Banks may instead have a desired capital buffer in excess of their requirement that they wish to keep constant. The second condition is that credit demand cannot be inelastic to allow for loan quantities to adjust following a regulatory change. Third, acquiring additional capital should be more expensive relative to debt. For this to be the case, the Modigliani-Miller theorem must not hold. The theorem states that if there are no frictions, changes in the composition of a bank's liabilities have no effect on funding costs, and as a result should have no effect on bank lending (Modigliani and Miller (1958)).[2] Kashyap et al. (2010) calibrate a model based on the Modigliani and Miller (1958) framework, in which the main difference in the cost of equity and debt financing is differential tax treatments. They find modest long-run impacts of higher capital requirements on lending rates with the cost of borrowing rising by only 25-45 basis points following a 10pp increase in capital requirements. Elliott (2009) also finds small impacts of capital requirements on loan volumes of US banks, while Miles et al. (2013) reach the same conclusion for UK banks.

Within the empirical literature, one category of papers has studied the response of banks to a capital requirement change.[3] My paper falls into this strand of the literature.

[1]For an overview of the theoretical literature on the impact of capital requirements, see VanHoose (2007, 2008).

[2]Examples of frictions are tax deductibility of debt (Modigliani and Miller (1958)) and asymmetric information that makes it costly to raise external equity (Myers and Majluf (1984)). Equity capital may also be more expensive due to ex-post verification costs (Diamond (1984), Gale and Hellwig (1985)).

[3]There is also a literature looking at the impact of capital shocks not driven by regulation (e.g. Bernanke et al. (1991), Peek and Rosengren (1997), Heid et al. (2004), Fonseca and González (2010),

Using a fixed effects framework, Aiyar et al. (2014) show that a 1pp rise in bank capital requirements is associated with a 5.7-8% decline in bank lending in the subsequent three quarters. Ediz et al. (1998) find, using a dynamic multivariate panel regression model and data from 1989-1995, that bank capital ratios do react to changes in required ratios, though much of the reaction is through adjusting capital rather than loan quantities. Bridges et al. (2014) study the impact of capital requirements on bank lending using UK data from 1989-2011. Using dynamic panel regressions, they find that changes in capital requirements do affect capital ratios. Following a tightening of requirements, banks rebuild their buffers by increasing their capital ratios over time. The authors also find heterogeneous responses of bank lending across sectors with commercial real estate lending growth showing the largest decline, followed by other corporate lending and then household secured lending. My paper builds on this by studying whether banks respond in other ways, in particular via capital accumulation or the risk composition of the asset portfolio. I use local projections à la Jordá (2005) to allow for greater flexibility in the shape of the impulse responses, and have a longer time dimension that allows for comparison of pre- and post-financial crisis responses. I also statistically test, using lasso methods, an assumption implicitly made in Bridges et al. (2014) and motivated by anecdotal evidence given in Aiyar et al. (2014) that changes in requirements can be treated as exogenous with respect to balance sheet risks and thus are orthogonal to other drivers of bank lending.

Francis and Osborne (2012) follow a different empirical approach initially introduced by Hancock and Wilcox (1993, 1994), and estimate a partial adjustment model whereby banks have a target capital ratio that depends on the regulatory requirement amongst other factors. Due to adjustment costs, they cannot adjust instantly or fully to their new target ratio. Using UK data, the authors find small effects of capital requirements on lending. de Ramon et al. (2022) apply this method to compare the pre- and post-crisis responses of banks to capital requirements. In line with our findings, they show that before the crisis, banks responded to changes in requirements via reductions in loan quantities and accumulation of capital, in particular Tier 2 capital. They show that banks have focused on capital accumulation as their primary adjustment tool since the

Jiménez et al. (2010) and Stolz and Wedow (2011)).

financial crisis. We find instead that banks have shifted to adjusting the risk composition of their assets.[4]

3 Institutional background

An appealing feature of the UK regulatory regime is that since 1989, supervisors have set bank- and time-varying minimum capital requirements in excess of the 8% requirement given by the Basel Accords.[5] The variation in the magnitudes and timing of capital requirement changes across banks, in addition to the fact that discretionary policy has been a feature of the UK supervisory regime for many years, makes the UK an appealing setting for studying the impact of capital requirements.

From 1997-2001, supervisors followed the Risk Assessment, Tools and Evaluation (RATE) framework (Financial Services Authority (1998)). It had three key stages as shown in Figure A.I: an initial formal risk assessment, a risk mitigation supervisory programme and the evaluation of the supervisory actions and outcomes. The risk assessment was based on nine evaluation factors that can be grouped into one of two categories: business risk and control risk. Business risk covered six quantitative factors and involved an analysis of the bank's financial position and key business.[6] Control risk determines the adequacy of the internal control framework and covers the remaining three qualitative factors.[7] Following an assessment of business and control risks, a supervisory programme was sent to the bank outlining the regulator's concerns and providing a set of actions that could include a new capital requirement. As such, a wide range of risks, both balance sheet and non-balance sheet risks, were covered within the RATE framework.[8] The

[4]Papers that have studied capital requirements outside of the UK include Mésonnier and Monks (2015), Jiménez et al. (2017), Fang et al. (2018), Gropp et al. (2018) and De Jonghe et al. (2019).

[5]Basel I introduced minimum capital requirements, whereby banks were required to satisfy a ratio of total regulatory capital to total risk-weighted assets of 8%, half of which needed to come from Tier 1 capital (Basel Committee on Banking Supervision (1988)). Iterations of the Basel Accords have since brought in changes to capital regulation. For details on Basel II and III, see Basel Committee on Banking Supervision (2006) and Basel Committee on Banking Supervision (2010a,b) respectively.

[6]The six quantitative factors are capital, asset quality, market risk, earnings, liabilities and liquidity profile, and business risk profiles.

[7]The three qualitative factors are internal controls, organizational structure and management.

[8]The intensity of the supervisory relationship was higher, the greater the perceived risk profile of a bank. The length of time between formal risk assessments was smaller at approximately 6-12 months for banks with high perceived risks compared to 18-24 months for banks with low risk profiles (Financial Services Authority (1998)). Figure A.II illustrates this concentration of resources towards "riskier" banks.

resulting capital requirement, set as a proportion of risk-weighted assets, was known as the *trigger ratio*.

In 2001, the FSA replaced RATE with ARROW (Advanced Risk Responsive Operation frameWork). An important difference of the ARROW framework relative to RATE is that under ARROW, the FSA followed a Risk to Our Objectives (RTO) approach, whereby the risk of interest to the FSA was not commercial risk taking per se, but rather the risk that the FSA's four statutory objectives would not be met. Indeed, "*it is not the role of the FSA to restrict appropriate risk-taking by regulated institutions or investors*" (Financial Services Authority (2000, p. 4)). The four objectives were: maintaining confidence in the UK financial system, promoting public understanding of the financial system, securing the appropriate degree of protection for consumers and reducing the scope for financial crime. As with RATE, business and control risks were evaluated and used for risk mitigation programmes that could include changes in capital requirements.[9] The Prudential Regulation Authority (PRA) was given responsibility over supervision in 2013.[10]

From this, it is clear that through the inclusion of control risks and the RTO approach of the FSA that capital requirement decisions were not based purely on balance sheet risks. There has been some anecdotal evidence discussed in Aiyar et al. (2014) suggesting that capital requirement decisions were mainly based on control risks, particularly in the pre-crisis era. The Turner Review stated that "*risk mitigation programs set out after ARROW reviews tended to focus more on organisation structures, systems and reporting procedures, than on overall risks in business models*" (Financial Services Authority (2009, p. 87)). Furthermore, Financial Services Authority (2008, p. 3) states that "*under ARROW I there was no requirement on supervisory teams to include any developed financial analysis in the material provided to ARROW Panels*". From this anecdotal evidence, it appears that capital requirement changes were orthogonal to balance sheet risks. I later provide statistical evidence using lasso regressions to support this. This institutional feature gives support to the identification assumption used in this paper that changes in capital requirements can be treated as exogenous with respect to other drivers of bank lending

[9] The FSA devoted attention and resources to the high impact banks (typically larger banks) as they were perceived to pose the greatest potential threat to the FSA's objectives (Financial Services Authority (2002), International Monetary Fund (2003)). Consequently, the probability assessment was not undertaken for low impact banks and they did not receive a risk mitigation programme.

[10] For further details on the PRA's supervisory framework, see Bank of England (2018).

and balance sheet composition.

4 Data

This paper uses the *Historical Banking Regulatory Database* (HBRD) constructed in de-Ramon et al. (2017). By extracting information contained in mandatory regulatory returns, HBRD contains balance sheet and confidential regulatory information for all regulated banks and building societies in the UK. The data is provided at both a consolidated/banking group level and a solo bank level, and spans 1989H1 to 2013H2.[11] Following Bridges et al. (2014) and de Ramon et al. (2022), I use the consolidated dataset for the analysis as lending and capital decisions are typically made at the banking group level.

The use of HBRD is especially beneficial for this work for a number of reasons: first, the dataset contains confidential information on individual bank capital requirements for the entire UK banking system. Second, the long time dimension allows for analysis of the medium-term impacts of capital requirements rather than focusing on the immediate-term response of banks. It also enables me to study whether bank responses to capital requirements have changed since the financial crisis. Third, HBRD contains over 100 analytical measures constructed using over 500 regulatory report items. The wide range of variables provides a large amount of information about each bank that would have been observable to the regulator and, as noted in Section 3, could be used when assessing bank risks and deciding on capital requirements. As such, this data is useful to statistically test whether balance sheet variables affect the regulator's capital requirement decision.[12]

A concern with the original raw dataset is the unbalanced nature of the panel associated with missing values and the entry/exit of banks throughout the sample. The raw dataset has 4,616 observations. I clean the original dataset using the steps described in Section B.1. The final dataset consists of 3,256 observations. Tables C.I and C.II provide details on the construction of key ratios and quantities used in the analysis.

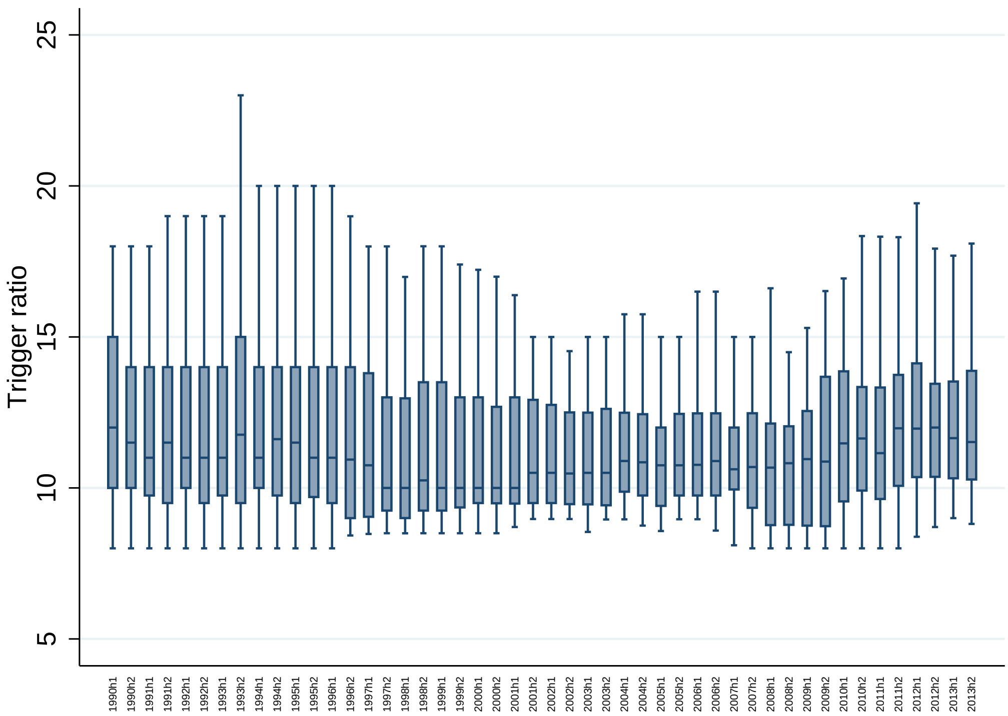
[11] For building societies, capital requirements data begins in 1997.

[12] One concern when using regulatory returns data over such a long period is changes in reporting frameworks and variable definitions. When constructing the HBRD, de-Ramon et al. (2017) use the instructions from each framework to construct consistent measures of variables over time.

5 Descriptive statistics

Table I provides summary statistics from the full sample. The average trigger ratio is 11.6%, which illustrates the use of discretionary capital requirements above the Basel I minimum of 8% by UK regulators. The high standard deviation of trigger ratios indicates the large cross-sectional variation in trigger ratios across banks. This is further highlighted in Figure I, which shows the distribution of trigger ratios over time. The largest trigger ratios declined in the years building up to the Great Recession and then increased in the years following it.

Figure I: Box plot of trigger ratios over time



Note: this figure shows the distribution of trigger ratios over time. The points correspond to the lower adjacent value, 25th percentile, median, 75th percentile and upper adjacent value.

In terms of capital requirement changes, Table I shows that there are 606 occurrences of capital requirement changes in the sample, making this almost a one-in-five event.[13] Although the median change is negative, the mean is slightly positive, suggesting that

[13] I classify a change as having occurred if the absolute value of the half-year change in trigger ratios exceeds 0.1pps.

Table I: Summary statistics

Variable	Obs	Mean	Std. Dev.	P10	P50	P90
Trigger ratio	3256	11.587	2.767	8.958	10.964	15
Change in trigger ratio (half-year, if change)	606	.045	1.181	-1.107	-.109	1.36
Tier 1 risk-based capital ratio	3256	19.22	16.078	7.353	12.896	43.414
Total risk-based capital ratio	3256	21.511	14.613	10.918	16.199	41.948
Capital buffer	3256	9.831	13.347	1.331	4.473	28.318
Assets growth (half-year)	3256	3.218	9.199	-8.584	3.57	14.553
Risk-weighted assets growth (half-year)	3256	2.807	9.005	-8.956	3.356	13.43
Average risk weight	3256	56.902	20.382	29.807	53.684	87.971
Liquid asset ratio	2829	10.731	10.722	.163	8.142	26.255
Tier 1 leverage ratio	3256	10.551	9.35	3.819	6.666	25.441
Solvency ratio	3256	179.306	98.471	113.293	141.812	317.349
Loans-to-assets ratio	3256	50.877	27.618	10.472	53.132	84.543
Tier 1 capital growth (half-year)	3255	3.193	8.334	-6.071	2.358	13.555
Total capital growth (half-year)	3256	3.047	8.038	-6.292	2.494	13.586
Loans growth (half-year)	3256	3.095	11.133	-11.24	3.655	16.735
Deposits growth (half-year)	3227	2.952	16.534	-13.88	3.196	20.294
Unsecured loans growth (half-year)	3155	4.583	33.645	-15.72	2.668	20.998
Residential loans growth (half-year)	2621	11.593	200.936	-17.783	3.367	25.698

Note: this table provides summary statistics based on the full sample. Columns 1-3 give the number of observations, mean and standard deviation for each variable. Columns 4-6 show the 10^{th}, 50^{th} and 90^{th} percentiles. "Trigger ratio" is the proportion of risk-weighted assets that banks must hold as capital. "Change in trigger ratio (half year, if change)" is the half-year change in the trigger ratio using only those observations where a capital requirement change occurred (a change is coded as having occurred if the half-year change exceeds 0.1pps in absolute value). "Average risk weight" is the ratio between risk-weighted assets and total assets. "Liquid asset ratio" is the ratio of liquid assets to total assets, where liquid assets here are defined as high quality liquid assets as well as credit to other financial institutions, debt securities and equity shares. "Tier 1 leverage ratio" is the ratio of Tier 1 capital to total assets. "Solvency ratio" is the ratio between total regulatory capital and total required capital, where total required capital is given by the trigger ratio multiplied by risk-weighted assets. "Unsecured loans growth" is the half-year growth of loans not secured on residential property.

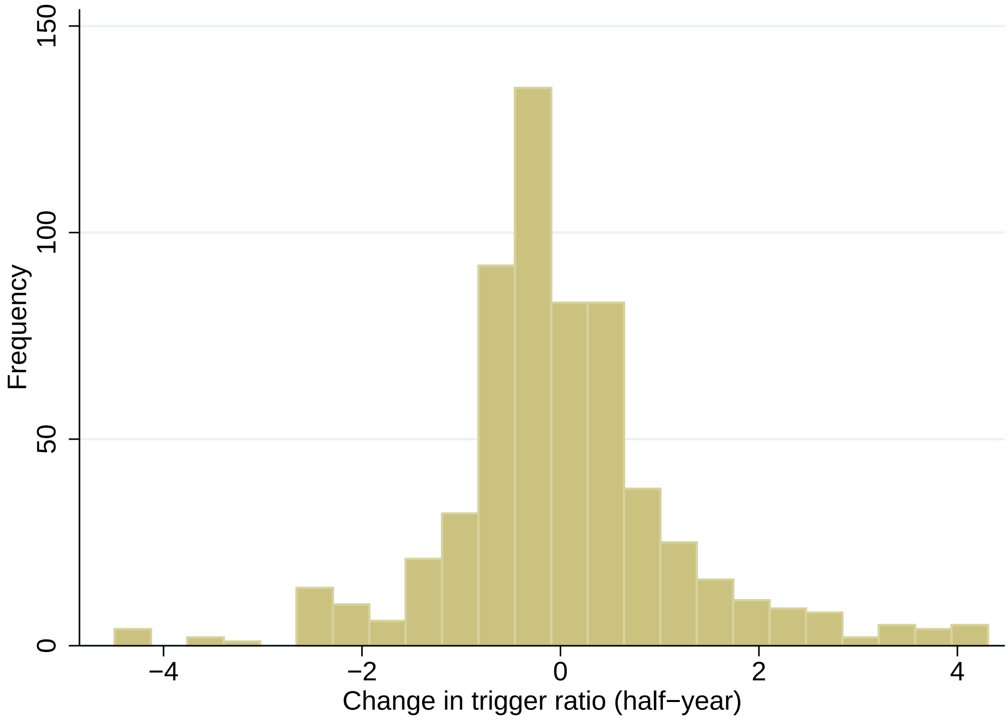
increases in capital requirements tend to be larger in magnitude than decreases. This is reinforced in Figure II, which shows the distribution of capital requirement changes. From this histogram, the rightward skew is clear. In order to see whether capital requirement changes tend to occur simultaneously across banks, Figure III plots the proportion of banks experiencing a change in their trigger ratio over time. While there are some periods when no trigger ratio changes occurred, namely pre-1995H2 and 2005H1-2006H2, there are regulatory changes in every other period, thus suggesting that capital regulation was active throughout the sample rather than only in specific periods. The frequency of trigger ratio movements appears to have increased since the Great Recession with around 50% of banks experiencing a change in each half year during the post-crisis period compared to less than 20% in most pre-crisis periods. A concern may be that trigger ratios move in the same direction for all banks experiencing a change. This could suggest that regulators are responding to business cycle fluctuations rather than individual bank characteristics. As noted in Meeks (2017) and shown in Figure IV, there are few periods where changes in capital requirements are of the same sign for all banks experiencing a regulatory change. Figure IV also shows that the spread of trigger ratio changes has risen since the crisis. The fact that the post-crisis period does not show purely positive changes in capital requirements indicates that increased supervisory attention rather than just tighter microprudential policy is a feature of the post-crisis period.

Although most UK banks face trigger ratios in excess of the 8% Basel I minimum risk-based capital ratio, many still hold capital buffers in excess of their requirements. Table I shows that the average capital buffer - computed as the difference between the risk-based capital ratio and the trigger ratio - is 9.8pps.[14] Figure V plots the distribution of capital buffers over time. Barring some banks in the first few periods of the sample, banks did not fall short of their required capital ratios, suggesting that capital regulation has been enforced. There is a large dispersion in capital buffers across banks with some banks operating close to their requirements and others holding substantial buffers.[15] It appears rare that a bank would operate with a capital ratio exactly equal to their requirement.

[14]Other papers have also shown that banks tend to have capital ratios in excess of regulatory minima, both in the UK and in other countries (e.g. Lindquist (2004), Jokipii and Milne (2008) and Shim (2013)).

[15]One reason for holding capital buffers is to avoid breaching capital requirements (see Alfon et al. (2004), Peura and Keppo (2006) and Francis and Osborne (2012)).

Figure II: Distribution of capital requirement changes

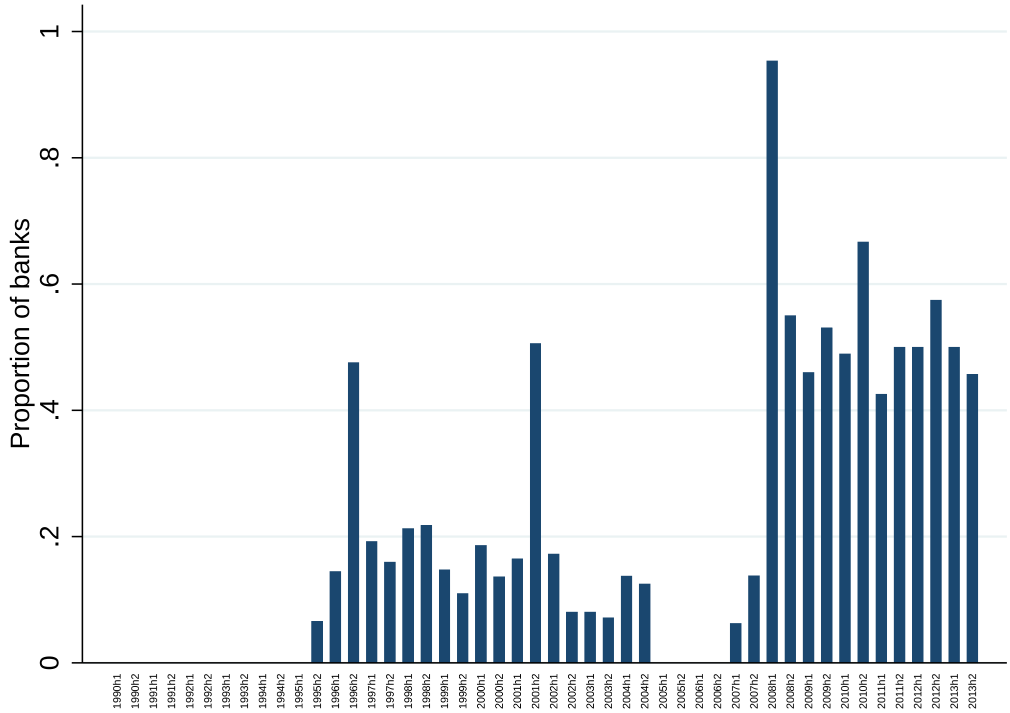


Note: this histogram shows the frequency of half-year changes in trigger ratios across a number of narrow bins for the full sample 1989H1-2013H2. I exclude observations with absolute changes of less than 0.1pps.

A feature of this box plot is that the distribution of capital buffers became much more concentrated in the years leading up to the Great Recession as banks originally holding the largest buffers reduced them. This could indicate countercyclicality of capital buffers.[16] Some evidence for countercyclicality of buffers is provided in Figure VI, which plots aggregate banking sector trigger and capital ratios over time. There was a slight decline in buffers from the 2000s and then a sharp rise during the recovery phase following the financial crisis. However, it should be noted that the rise in buffers coincides with increasing supervisory attention following the Great Recession and so perhaps cannot be completely attributed to business cycle fluctuations. A notable takeaway from the figure is that aggregate trigger ratios have been very stable at just under 10% until around 2010, after which there was a small rise to just over 10%, a feature also documented in

[16] Some evidence for countercyclicality is provided in Stolz and Wedow (2011) for German banks, Ayuso et al. (2004) for Spanish banks and Shim (2013) for US banks. However, there are also papers giving evidence of procyclicality of capital buffers, e.g. Montagnoli et al. (2018) for Portuguese banks and Valencia and Bolaños (2018) for developing countries.

Figure III: Proportion of banks experiencing changes in trigger ratios over time



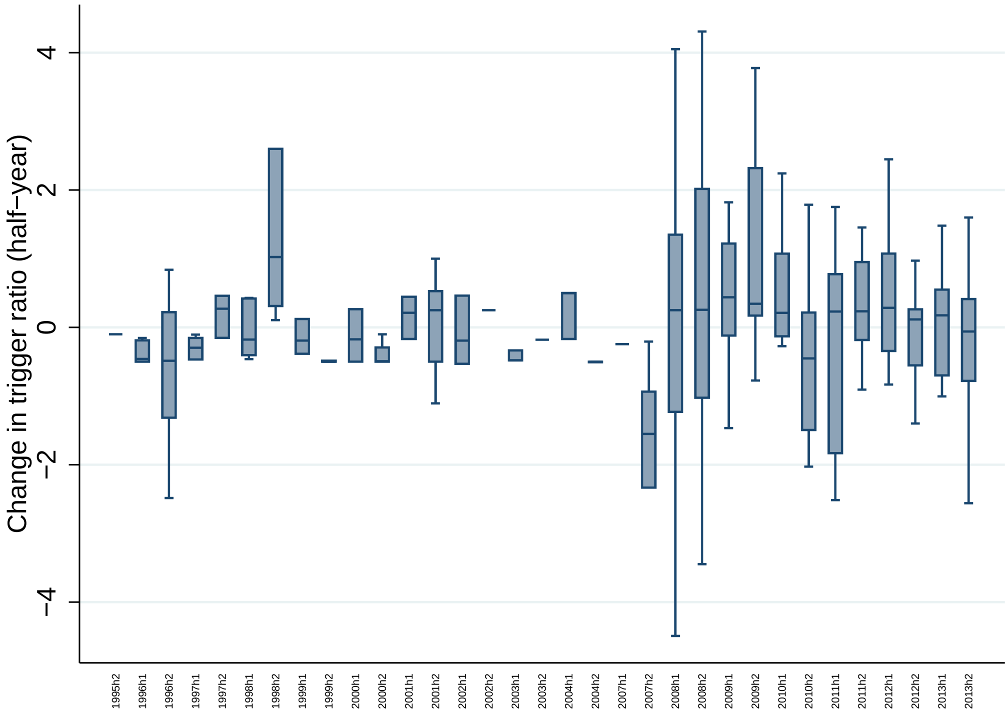
Note: this figure shows the proportion over time of banking groups who experienced a change in trigger ratios in a given period. A change is coded as having occurred if the absolute change in trigger ratios is more than 0.1pps relative to the previous half year.

de-Ramon et al. (2017). This suggests that much of the action of capital requirements in the UK has been at the micro rather than macro level.

6 Method

A priori, there are concerns with treating changes in trigger ratios as exogenous. One may expect changes in trigger ratios to be correlated with balance sheets risks. For example, a bank that undertakes riskier lending would be subject to greater credit risk, thus leading to different behavior compared to banks undertaking less risky lending. The increased credit risk may concern the regulator, leading to a higher capital requirement. There is thus a selection problem as it can be difficult to separately identify the causal effect of capital requirements from the potentially different nature of those banks receiving a tighter capital requirement. I therefore begin by empirically testing the assumption made

FIGURE IV: Box plot of changes in trigger ratios over time



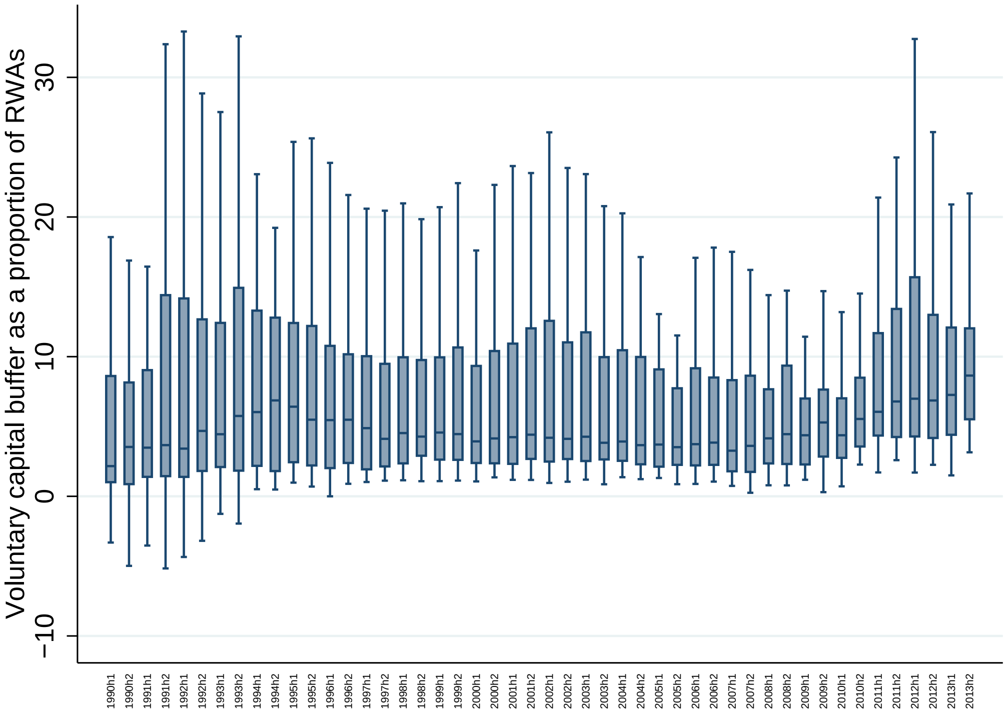
Note: this figure shows the distribution of half-year changes in trigger ratios over time. The points correspond to the lower adjacent value, 25^{th} percentile, median, 75^{th} percentile and upper adjacent value. I exclude values of trigger ratio changes with absolute values less than 0.1pps.

in Aiyar et al. (2014) and Bridges et al. (2014) that changes in capital requirements are orthogonal to balance sheet risks. Using the least absolute shrinkage and selection operator (lasso) of Tibshirani (1996), I test whether key balance sheet variables enter into the regulator's reaction function. Upon verifying this assumption, I employ the local projection method of Jordá (2005) to trace out impulse responses of capital ratios and its subcomponents to a capital requirement change.

6.1 Lasso regressions

A major advantage of the HBRD dataset is that it contains a large amount of bank-level information that would have been observable to the regulator when setting requirements. I use lasso regressions to establish whether regulators consider balance sheet variables

Figure V: Box plot of capital buffers over time



Note: this figure shows the distribution of capital buffers over time. Capital buffers are calculated as the difference between a bank's risk-based capital ratio (total regulatory capital divided by total risk-weighted assets) and its trigger ratio. The points correspond to the lower adjacent value, 25$^{\text{th}}$ percentile, median, 75$^{\text{th}}$ percentile and upper adjacent value.

when setting banks' trigger ratios.[17] The standard lasso estimator minimizes the following objective function:

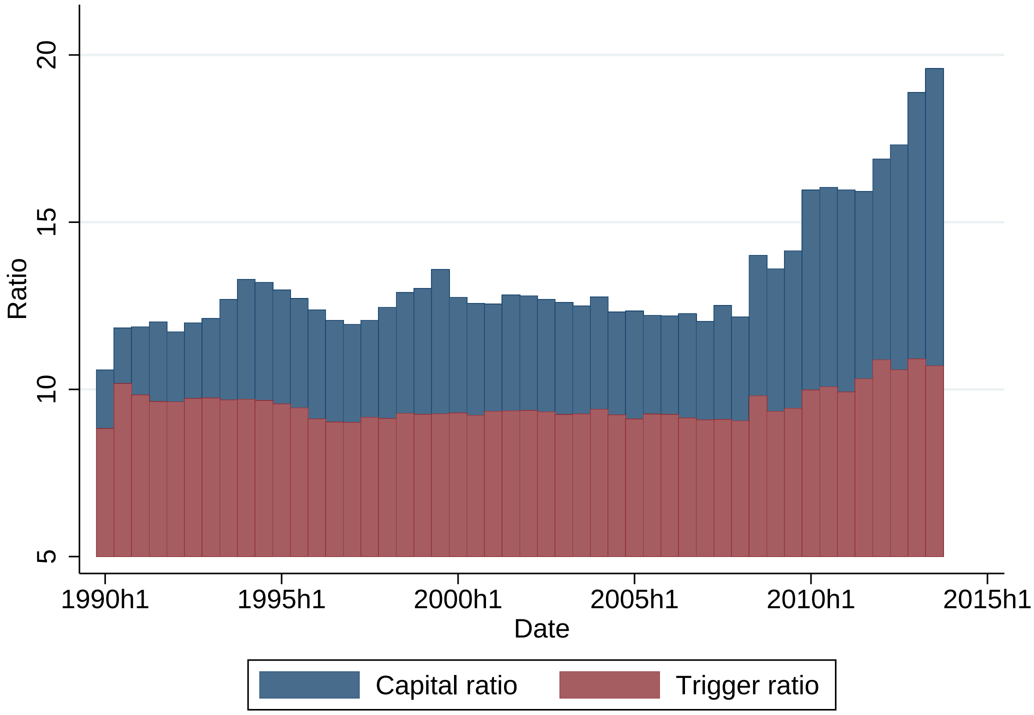
$$\arg\min_{\boldsymbol{\beta}} \frac{1}{N}\sum_{i,t}(y_{it} - \mathbf{x}'_{it}\boldsymbol{\beta})^2 + \frac{\lambda}{N}\|\boldsymbol{\beta}\|_1$$

where $\|\boldsymbol{\beta}\|_1 = \sum_{j=1}^{J}|\beta_j|$, λ is the key penalization parameter and N is the number of observations used in the estimation. As such, the lasso regression seeks to minimize the residual sum of squares like in OLS estimation; however, unlike OLS it imposes an $\ell 1$-penalty on the coefficients. This penalty term shrinks the coefficients, some of which are shrunk down to zero, thus yielding sparse solutions and aiding model interpretation.[18] To

[17] I use the *lassopack* Stata package of Ahrens et al. (2018) for lasso estimation.

[18] Alternative approaches to variable selection include stepwise techniques, best subset selection methods and least angle regression. There is no consensus over which approach should be preferred, particularly when there are a large number of explanatory variables (see Bertsimas et al. (2016) and Hastie et al. (2017) for further discussion).

FIGURE VI: Time series of aggregate trigger and capital ratios



Note: this figure shows a time series of aggregate risk-based capital ratios and trigger ratios. Aggregate ratios are calculated as a weighted average of the individual bank ratios using total assets as weights.

obtain λ, I use K-fold cross-validation, which repeatedly partitions data into training and validation data and chooses the λ that minimizes an estimated mean squared prediction error (MSPE).[19] Section B.2 describes the steps involved in the cross-validation procedure. I set $K = 10$ in the baseline analysis, but provide robustness checks using alternative values of K in Section 8.[20].

In my setting, y_{it} is the half-year change in trigger ratio, while $\mathbf{x}_{it}$ contains the one-period lag of annual growth rates or ratio changes of 30 bank balance sheet variables.[21] Table C.I provides the full list of variables.[22] The use of the one-period lag reflects lags associated with collating and communicating information about the bank to the

[19] Alternative methods for selecting λ are discussed in Section 8.

[20] $K = 10$ is viewed to perform well on model selection (see Breiman and Spector (1992); Kohavi (1995); Zou (2006))

[21] A within transformation on all predictor variables ($\mathbf{x}$) is applied before doing the lasso regressions.

[22] As the lasso constraint involves the sum of absolute values of the $\boldsymbol{\beta}$ coefficients not exceeding some value, the variables in $\mathbf{x}_{it}$ are standardized to have zero mean and unit variance to ensure they are of the same scale. Note that only data in the training dataset is used when standardizing.

regulator. I use annual rather than half-year movements in order to capture a general trend in bank behavior rather than higher frequency movements that could be driven by a temporary shock. Time dummies are included in $\mathbf{x}_{it}$ to capture sector-wide changes in capital requirements associated with, for example, macroeconomic fluctuations.[23]

6.2 Impulse responses following a capital requirement change

I apply local projections (Jordá (2005)) to trace out impulse responses of the capital ratio and its subcomponents. Under local projections, the model is estimated separately for each horizon h, thus allowing for flexibility in the shape of the impulse responses.[24] For each $h \in \{0, 1, ..., H\}$, I estimate the following model:

$$y_{i,t+h} - y_{i,t-1} = \beta_0^{(h)} + \beta_1^{(h)} \Delta trigger_{i,t} + \sum_{l=1}^{L} \delta_l^{(h)} \Delta y_{i,t-l} + \sum_{l=0}^{L} \boldsymbol{\eta}_l^{(h)} \Delta \mathbf{x}_{i,t-l} + \alpha_i^{(h)} + \gamma_t^{(h)} + \nu_{i,t}^{(h)} \quad (1)$$

where $y_{i,t+h}$ denotes the value of the variable of interest for bank i at time $t+h$, $\Delta trigger_{i,t}$ is the half-year change in trigger ratio and $\mathbf{x}_{i,t-l}$ denotes a vector of controls for bank i in period $t-l$.[25] Lags of $\Delta y_{i,t-l}$ are included to sweep up serial correlation, and L denotes the maximal lag for the controls and the lags of $\Delta y_{i,t}$. $\alpha_i^{(h)}$ and $\gamma_t^{(h)}$ denote bank and time fixed effects respectively. I include the Tier 1 capital ratio and Tier 1 leverage ratio in the vector of controls, $\mathbf{x}_{i,t-k}$, and set $L = 2$.

The impulse response of a variable y is given by plotting the estimates $\hat{\beta}_1^{(h)}$ over h. I take $H = 6$ such that the impulse responses look at the effect of capital requirements over a three-year period. For the estimates to be causal, I require that changes in trigger ratios are orthogonal to other bank- and time-varying drivers of the outcome of interest. The validity of this assumption is discussed in Section 7.1.

[23] Time dummies are partialled out prior to the lasso estimation in order to keep them in the final model. Partialling out a variable is equivalent to not penalizing that variable (Yamada (2017)).

[24] An advantage of local projections over vector autoregressions is that the former does not impose a dynamic structure, making it more robust to misspecification and less susceptible to the curse of dimensionality (Barnichon and Brownlees (2016)).

[25] If y is a quantity variable such as total loans or total regulatory capital, it is transformed into logs prior to estimation such that $y_{i,t+h} - y_{i,t-1}$ gives the cumulative growth from period $t-1$ to period $t+h$. No transformation is applied when y is a ratio.

7 Results

7.1 Baseline regressions

In the baseline specification, I pool together all banks, thus assuming that the reaction functions of the regulator and the response of banks to a capital requirement change are common across banks. Table II shows the reaction function of the regulator following the lasso estimation. None of the 30 balance sheet variables included in the lasso are selected to feature in the reaction function. This finding is in line with the anecdotal evidence described in Section 3 which suggests that FSA regulators focused more on control risks such as IT systems rather than balance sheet risks. Together, this suggests that much of the variation in capital requirement changes comes from control risks, and so the assumption required for my estimates to be causal is for control risks to be orthogonal to balance sheet risks.

Table II: Lasso-selected reaction function of the regulator (baseline specification)

	(1)
Constant	-0.00361
	(0.011)
Time fixed effects	Yes
Bank fixed effects	Yes
Observations	3256
Number of banking groups	212
R-squared	0.06

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors in parentheses. This table shows the lasso estimation following Section 6.1. The dependent variable is the half-year change in trigger ratio. The variables that appear in the lasso estimation are given in Table C.I. An intercept and bank and time fixed effects are included.

Figure VII plots the impulse responses following a 1pp capital requirement increase under the baseline specification. The first key result is that there is a significant rise in capital ratios by just under 0.5pps immediately, showing that there is an instant, but partial, adjustment. The coefficient estimate remains stable and positive throughout. As far as three years later, capital ratios remain about 0.5pps larger than the pre-shock level. The next step is to understand which components of capital ratios adjust. Risk-based capital ratios can be decomposed as:

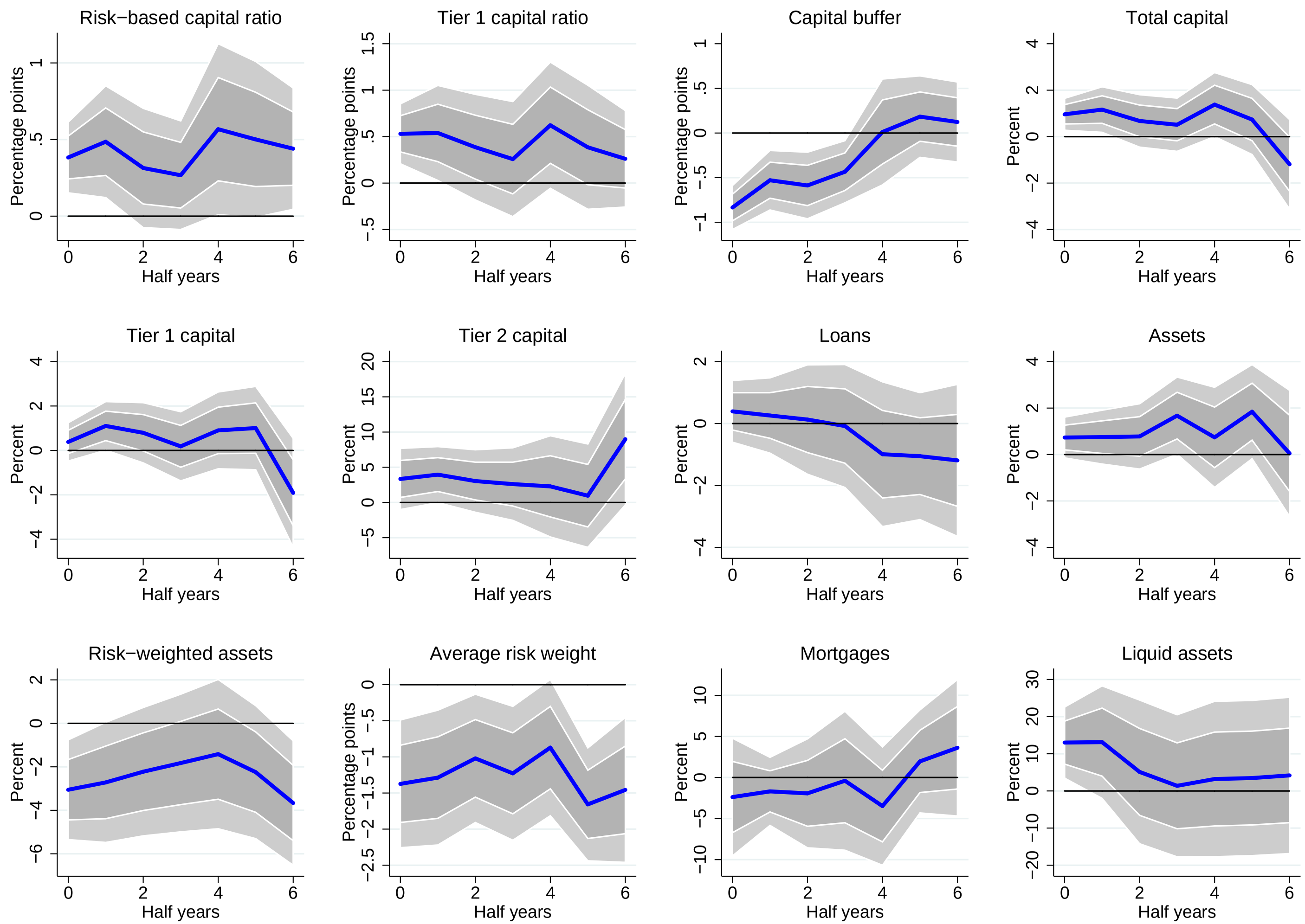
$$\begin{aligned}\text{Risk-based capital ratio} &= \frac{\text{Total regulatory capital}}{\text{Risk-weighted assets}} \\ &= \frac{\text{Total regulatory capital}}{\text{Total assets}} \times (\underbrace{\frac{\text{Risk-weighted assets}}{\text{Total assets}}}_{\text{Average risk weight}})^{-1}\end{aligned}$$

I can thus analyse whether the adjustment is mainly through a quantity effect, whereby the quantity of total regulatory capital and/or assets changes, or whether there is a shift in the risk composition of the bank's assets. The second key result is that there is a quantity effect for capital, but not for assets. From Figure VII, there is a significant increase in total regulatory capital of around 1% after one year. Tier 2 capital increases by just under 4% after a year compared to a rise of around 1% for Tier 1 capital. Given that Tier 2 capital is of lower quality and thus cheaper than Tier 1 capital, the decision of banks to use this type of capital makes sense from a cost-minimization perspective. Indeed, Francis and Osborne (2012) and de Ramon et al. (2022) also find that banks adjust through Tier 2 capital instruments. If anything, total assets rise following a capital requirement increase, which would lower capital ratios. The levels of loans and mortgages do not change significantly, suggesting that banks do not cut lending in response to a rise in capital requirements. Instead, liquid assets increase, which gives some evidence for a switch to less risky assets and can explain the rise in total assets. This risk composition effect is highlighted when looking at risk-weighted assets and average risk weights. The immediate-term reaction of risk-weighted assets is a decline of around 3%. Given that total assets, if anything, increase, there is a clear significant drop in average risk weights of around 1-1.5pps. As such, the third key finding is that the quantities of assets and loans do not fall in response to a rise in capital requirements; however, there is a composition effect towards less risky assets.

7.2 Heterogeneity analysis

In this section, I conduct micro-level heterogeneity analysis, redoing the lasso estimation and impulse responses for different subsamples based on time period (pre- vs. post-crisis), the direction of the capital requirement change and bank size. Summary statistics

FIGURE VII: Impulse responses to a 1pp capital requirement increase



Note: this figure shows the local projection impulse responses from estimation of Equation 1 for twelve bank variables following a 1pp increase in capital requirements. Table C.II gives further details on the dependent variables. 68% and 90% confidence intervals are shown.

based on these subsamples are given in Tables C.III to C.V. First, I examine whether the reaction to a capital requirement change differs before and after the financial crisis.[26] As shown in Table C.VI, the lasso-selected model does not include any individual balance sheet variables. Figure C.I shows the impulse responses following a 1pp capital requirement increase. There are some notable differences in the two responses: first, the response of capital ratios is much more delayed in the pre-crisis period with risk-based capital ratios remaining unchanged until 18 months after the shock when there is a complete pass-through, meaning that banks completely dug into their capital buffers until then. In contrast, there is an immediate significant, but incomplete, pass-through into risk-based capital ratios in the post-crisis period. The swifter response could reflect greater supervisory intensity since the crisis. The second difference is that the pre-crisis response is particularly driven by capital accumulation, while the risk composition channel that was significant in the full sample results appears to be a post-crisis phenomenon. For the pre-crisis sample, the change in average risk weights is statistically insignificant for most horizons, while there is a significant drop during the first two years for the post-crisis period. The quantities of total assets and loans hardly change in the post-crisis period. However, there is a significant decline in total loans after two years for the pre-crisis period and so the quantity effect in assets plays more of a role here.

Next I look at whether banks behave differentially to a loosening versus a tightening of their capital requirements. I split changes in trigger ratios (after bank and time fixed effects have been stripped out) into positive and negative values. Figure C.II shows the impulse responses from this exercise. There are also differences between the two sets of responses here: first, capital ratios only adjust to declines in capital requirements. For an increase, banks respond by digging into their buffers. One concern with this result is that banks operating at their minimum requirement should adopt a complete pass-through of an increase in requirements. As such, the null overall effect would suggest that banks holding capital buffers have a negative pass-through, which would be unusual. However, there are very few banks operating with no or very small buffers. Figure V and Table I show that most banks do hold a buffer with the median buffer being almost 4.5pps. Even

[26] Pre-crisis observations are taken to be before and including 2007H1, and thus are all prior to the unravelling of interbank markets that arguably began with BNP Paribas stopping withdrawals from three investment funds on 9^{th} August 2007.

at the 10$^{\text{th}}$ percentile, the buffer is over 1pp, so almost all banks could absorb a 1pp rise in requirements through their buffers. While a further decomposition separating banks with very small buffers would be interesting, the limited number of such banks would make estimation imprecise. Second, the risk composition channel holds for declines in capital requirements, but not increases. Following a loosening of requirements, the average risk weight increases, suggesting that banks move into riskier asset classes. However, other than in the immediate term, the average risk weight does not fall following a tightening of requirements.

I now look at whether small banks react differently to large banks to a capital requirement shock. I divide the sample based on the median value for total assets by each half-year period. Whilst such a distinction is naturally of interest, bank size is also an important determinant of the resource allocation of regulators as described in Section 3. For smaller banks, much of the risk assessment is through baseline monitoring of regulatory returns, while for larger banks, factors such as on-site visits also play a role. As a result, it is possible that balance sheet risks identified using regulatory returns play a larger role when deciding upon small banks' capital requirements. Table C.VII shows the lasso-selected model, but again gives the result that no individual balance sheet variables are selected, even for small banks.[27] Figure C.III shows that much of the reaction to capital requirement changes comes from small banks. I find that for small banks, risk-based capital ratios rise by around 0.5pps after one year, while for large banks, there is no adjustment of risk-based capital ratios during the first 18 months. As a result, there is a larger depletion of capital buffers for large banks during this phase. The reaction of small banks appears to come through a combination of two channels, namely a quantity effect for capital and a risk composition effect towards less risky assets, but not a quantity effect for total assets or loans. The significant rise in total capital of over 1% seems to be predominantly through Tier 2 rather than Tier 1 capital, although the latter does show a significant increase too. For large banks, there is no significant change in total capital until two years after the regulatory change, which is in line with the behavior of risk-based capital ratios. Total assets, if anything, increase over time, meaning there is

[27] This result is robust to using the 75$^{\text{th}}$ and 90$^{\text{th}}$ percentiles for total assets to separate small and large banks.

no quantity effect in total assets. There is a slight decline in average risk weights, but this is much smaller than for small banks. As such, compared with small banks, the reaction of large banks is much more delayed and comes predominantly through capital accumulation with a small risk composition effect. However, as shown in the summary statistics by size of bank in Table C.V, there are significant differences between the two subgroups other than total assets. For example, large banks seem to have smaller capital buffers, loan-to-assets ratios and solvency ratios, all of which may interact with the response to a capital requirement shock. As such, the results for small versus large banks should be taken lightly as it will require a larger sample size to split the subgroup further in order to isolate the impact of bank size with reasonable precision.

8 Robustness

One concern with the methodology used in this paper is whether lasso techniques are appropriate for model selection. A necessary and sufficient condition for consistent variable selection is for the *irrepresentable condition* to be satisfied (Meinshausen and Bühlmann (2006); Zhao and Yu (2006); Zou (2006)). This condition requires the correlation between variables inside the regulator's actual reaction function and variables outside of the true model to be sufficiently low.[28] To explain intuitively why this condition is needed, suppose that there are two highly correlated variables, but only one enters into the true reaction function. The lasso procedure may then select the other variable as a result of the high correlation, leading to incorrect conclusions for variable selection. This would be irrespective of the sample size or the degree of regularization. In my setting, it is arguably

[28] More formally, the irrepresentable condition is as follows: denote $\hat{\Sigma} \equiv n^{-1}\mathbf{X}^T\mathbf{X}$ and define $S_0 = \{j : \beta_j \neq 0\}$ as the set of variables that do belong in the true model. Without loss of generality, suppose $S_0 = \{1, 2, ..., s_0\}$, so the set S_0 contains the first s_0 variables. Writing in block form:

$$\hat{\Sigma} = \begin{pmatrix} \hat{\Sigma}_{1,1} & \hat{\Sigma}_{1,2} \\ \hat{\Sigma}_{2,1} & \hat{\Sigma}_{2,2} \end{pmatrix}$$

where $\hat{\Sigma}_{1,1}$ is an $s_0 \times s_0$ matrix for those variables in S_0, $\hat{\Sigma}_{1,2} = \hat{\Sigma}_{2,1}^T$ is an $s_0 \times (p - s_0)$ matrix (where p is the total number of variables) and $\hat{\Sigma}_{2,2}$ is a $(p - s_0) \times (p - s_0)$ matrix. The irrepresentable condition states:

$$|\hat{\Sigma}_{2,1}\hat{\Sigma}_{1,1}^{-1}\text{sign}(\beta_1, ..., \beta_{s_0})| \leq \boldsymbol{\theta}$$

where $\boldsymbol{\theta}$ is a $(p - s_0) \times 1$ column vector with each element $0 < \theta_j < 1$ and $\text{sign}(\beta_1, ..., \beta_{s_0}) = (\text{sign}(\beta_1), ..., \text{sign}(\beta_p))^T$. The inequality must hold element-wise.

difficult to satisfy the irrepresentable condition as decisions of banks across a wide range of balance sheet variables are likely to be correlated. I therefore apply the adaptive lasso of Zou (2006), which is consistent for variable selection under weaker assumptions. The adaptive lasso involves a two-step procedure: first, an initial estimator $\hat{\boldsymbol{\beta}}_{\text{initial}}$ is obtained using a standard fixed effects regression:

$$y_{it} = \boldsymbol{x}_{it}'\boldsymbol{\beta} + \alpha_i + \gamma_t + \epsilon_{it}$$

where y_{it} is the half-year change in trigger ratio for bank i at time t and $\boldsymbol{x_{it}}$ is the vector of all 30 balance sheet variables. The adaptive lasso estimator is then:

$$\hat{\boldsymbol{\beta}}_{\text{adaptive}} = \arg\min_{\boldsymbol{\beta}} \frac{1}{N}\sum_{i,t}(y_{it} - \mathbf{x}_{it}'\boldsymbol{\beta})^2 + \frac{\lambda}{N}\sum_{j=1}^{p}\frac{|\beta_j|}{|\hat{\beta}_{\text{initial},j}|^{\theta}}$$

where as in Section 6.1, a within transformation is applied to the regressors $\mathbf{x}$ and time fixed effects are partialled out prior to estimation. λ is again obtained through cross validation and I take $\theta = 1$. Column 1 of Table C.VIII shows that the adaptive lasso also selects no variables.

I also consider other lasso variants. As an alternative to cross validation for the selection of the penalization parameter λ, I also use the clustered rigorous lasso of Belloni et al. (2016), which provides a theoretically-driven and data-dependent penalization:

$$\lambda = 2c\sqrt{N}\Phi^{-1}(1 - \frac{\gamma}{2p})$$

where γ is the number of clusters (i.e. the number of bank groups in the sample) and $c = 1.1$. p is the number of penalized variables in the lasso (in my case, 30) and Φ^{-1} is the inverse normal CDF function. The results from this are given in Column 2 of Table C.VIII. Column 3 gives the model selected through the Extended Bayesian Information Criteria (EBIC) of Chen and Chen (2008). In both cases, the lasso procedure again selects no variables. Columns 4-7 consider K-fold cross validation for different values of K (in the baseline specification, I use $K = 10$). In all cases, no variables are chosen.

A further concern is that the full sample contains observations where a supervisory review may not have taken place in that period. Including these observations could make it difficult to identify the regulator's reaction function. As described in Section 3, supervisory reviews tend to occur at fixed time intervals of every 1-3 years. If the supervisory review dates were recorded, one could simply exclude observations where a review recently took place or focus on observations when a review did occur. However, these dates are not recorded in the dataset. I provide two proxy approaches based on observed changes in capital requirements. Column 8 shows the selected model under the baseline approach using only those observations for which a change actually took place. Here no variables are selected. Column 9 considers only those observations where there are no observed changes in trigger ratios in the previous 12 months given the supervisory cycle length of 1-3 years. In this case, more balance sheet variables are selected. In particular, lower risk-weighted asset growth and higher unsecured loans and non-performing loans growth rates are associated with higher capital requirements. Figures C.IV and C.V show the impulse responses for these two samples.[29] The main findings from the baseline specification of Figure VII appear to hold in both cases, although a medium-term quantity effect for loans appears to occur when using observations where no requirement change occurred in the preceding 12 months.

9 Conclusion

A growing interest in micro- and macroprudential regulation and their impacts on the banking sector has emerged since the financial crisis. This paper seeks to quantify the effect of one particular tool, namely bank capital requirements. Using confidential data on individual bank capital requirements in the UK from 1989H1-2013H2, I study the impact of changes in individual bank capital requirements on bank balance sheet behavior. I first show using lasso techniques that changes in capital requirements appear orthogonal to balance sheet risks. Using local projections à la Jordá (2005), I then trace out the impulse responses of capital ratios and its subcomponents over a three-year window following a capital requirements change.

Using the full sample of banks, I find that, on average, banks do adjust their actual

[29] For the specification with no changes in trigger ratios in the past 12 months, changes in capital ratios are stripped of the lasso-selected balance sheet variables and bank and time fixed effects, and the residuals are used in the impulse responses.

capital ratios following a change in requirements, but only partially with a pass-through of around 50%. Much of this reaction comes through capital accumulation, in particular the level of Tier 2 capital; however, the quantity of loans is unchanged. There is also evidence of a composition effect, whereby banks adjust the average riskiness of their asset portfolio. Banks only react to decreases in capital requirements with an increase in requirements being absorbed by banks' pre-existing capital buffers. Comparing the impact of a capital requirement change in the pre- and post-financial crisis periods, I find that the pre-crisis response is characterized by quantity effects in capital and loans, but no composition effect. In particular, total lending falls by 5% on average one year after a 1pp increase in capital requirements. Instead, the post-crisis period is associated with no significant change in the quantity of loans, though there is a composition effect towards less risky assets.

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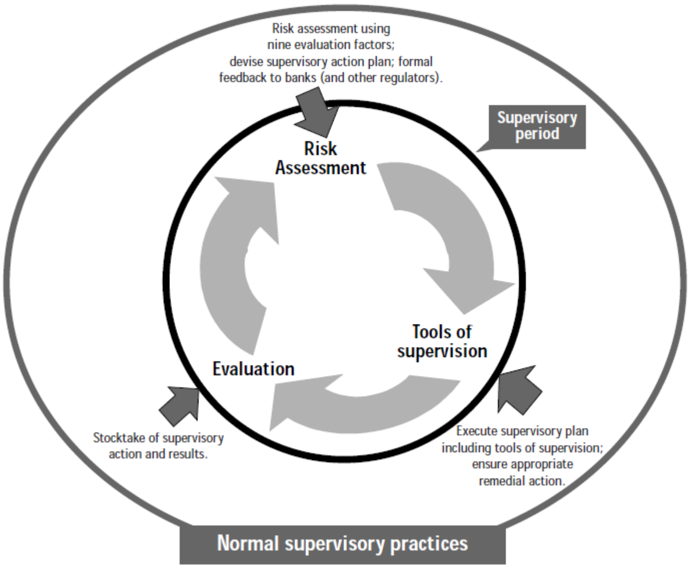
Appendix

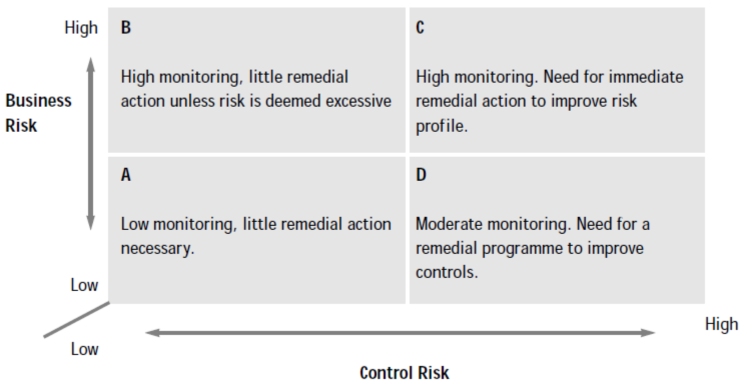
A Supervisory frameworks

Figure A.I: RATE framework process



Note: this figure provides an overview of the FSA's RATE (Risk Assessment, Tools and Evaluation) framework, and is taken from Financial Services Authority (1998). Further details of the UK supervisory frameworks are provided in Section 3.

Figure A.II: Supervisory intensity under the FSA's RATE framework



Note: this matrix gives a summary of the likely supervisory intensity following different combinations of business and control risk profiles. Figure is taken from Financial Services Authority (1998). Further details of the UK supervisory frameworks are provided in Section 3.

B Methodology details

B.1 Data cleaning steps

1. There are missing values in the dataset. These can either be specific variables missing in the otherwise-completed returns, or no returns at all for that bank in the given half year.[30] I linearly interpolate the data whenever there is a missing value for a variable, but data is available for the two periods on either side of that date.

2. Different banks file returns at different times in the year with the convention being June and December reporting. The varying length of one period for each bank makes it difficult to analyse the impact of capital requirements over different horizons. I use linear interpolation to align reporting period ends to the June/December convention such that one period corresponds to six months for all banks.

3. I replace suspicious zeros with missing values and use absolute values when a negative number is reported for a variable that should only permit weakly positive values.

4. I treat the banking group resulting from mergers and acquisitions as a new banking group as in de Ramon et al. (2022). Due to different financial structures, business strategies and management following such activity, it would not be appropriate to treat the resulting banking group as the same entity. In addition, I create a new institution whenever the half-year growth of total assets, loans or regulatory capital exceeds 50% in order to capture structural changes not covered by the identification of mergers in HBRD.[31]

5. To mitigate the impact of outliers, I drop observations where the half-year growth of total regulatory capital, assets or loans exceeds 50%, or if the half-year change in the trigger ratio exceeds 10pps. I also winsorize all variables at the 5^{th} and 95^{th} percentiles of a given half year.

[30] In cases where entire reports are missing, this is typically due to special waivers being granted or because the regulator did not supervise the bank until a later period.

[31] An example of such a change is the merger of NatWest with Royal Bank of Scotland in 2000. A similar approach is also taken in de Ramon et al. (2022).

B.2 Steps for K-fold cross-validation

The steps are as follows:

1. Data is partitioned into K folds of roughly equal size.

2. The first fold becomes the validation dataset and the other $K - 1$ folds make the training dataset. For a given λ, the model is fit to the training data. Denoting the coefficient estimates from this step as $\hat{\beta}_{1,\lambda}$, the MSPE for fold 1 is:

$$MSPE_{1,\lambda} = \frac{1}{n_1} \sum_{i,t}^{n_1} (y_{it} - \mathbf{x}'_{it} \hat{\boldsymbol{\beta}}_{1,\lambda})$$

   Note that you sum over only those observations belonging to the validation dataset, which in this case are observations in fold 1.

3. Repeat the process using different folds as the validation dataset and compute $MSPE_{k,\lambda}$ for $k = 2, 3, ..., K$.

4. For a given λ, the K-fold cross-validation estimate of the MSPE, CV_λ, provides a measure of prediction performance and is computed as:

$$CV_\lambda = \frac{1}{K} \sum_{k=1}^{K} MSPE_{k,\lambda}$$

5. Repeat the above steps for multiple values of λ. The chosen λ, denoted as λ^*, is then:

$$\lambda^* = \arg\min_{\lambda} CV_\lambda$$

C Data and results

Table C.I: Variables used in lasso regressions

Variable	Formula	Notes
Change in losses to loans ratio	$100 \times \Delta_2(\frac{\text{Write offs net of recoveries}}{\text{Loans}})$	Seasonally-adjusted value of net write-offs used.
Change in provisions to loans ratio	$100 \times \Delta_2(\frac{\text{Provisions}}{\text{Loans}})$	Total provisions includes specific and general provisions against bad or doubtful debt.
Change in impairments to assets ratio	$100 \times \Delta_2(\frac{\text{Impairments charge}}{\text{Assets}})$	Impairments charge is seasonally adjusted and includes the net charge or credit to the P&L account for the provision for doubtful debts.
Change in average risk weight	$100 \times \Delta_2(\frac{\text{RWA}}{\text{Assets}})$	
Change in loans to assets ratio	$100 \times \Delta_2(\frac{\text{Loans}}{\text{Assets}})$	Total loans includes all funds lent to counterparties other than credit institutions, central governments and central banks.
Change in loans to deposits ratio	$100 \times \Delta_2(\frac{\text{Loans}}{\text{Deposits}})$	Total deposits covers all intra-financial and retail deposits.
Change in liquid asset ratio	$100 \times \Delta_2(\frac{\text{High quality liquid assets}}{\text{Assets}})$	High quality liquid assets cover cash and balances at central banks, gilts, Treasury bills and other highly liquid bills.
Change in Tier 1 leverage ratio	$100 \times \Delta_2(\frac{\text{Tier 1 capital}}{\text{Assets}})$	
Change in solvency ratio	$100 \times \Delta_2(\frac{\text{Capital}}{\text{Required capital}})$	Capital is total regulatory capital held by the bank. Total required capital is given by the trigger ratio multiplied by total risk-weighted assets.

Change in efficiency ratio	$100 \times \Delta_2(\frac{\text{Overhead costs}}{\text{Non-interest income}})$	Total overhead costs include staff expenses, administrative costs and other operating expenses. Total non-interest income includes net-interest income, fee and commission income, other operating income and trading income.
Change in residential loans to assets ratio	$100 \times \Delta_2(\frac{\text{Residential}}{\text{Assets}})$	Total residential loans are all loans secured on residential property.
Change in capital buffer	$100 \times \Delta_2(\frac{\text{Capital}-\text{Required capital}}{\text{Required capital}})$	
Change in capital ratio	$100 \times \Delta_2(\frac{\text{Capital}}{\text{Assets}})$	
Change in Core Tier 1 capital ratio	$100 \times \Delta_2(\frac{\text{Core Tier 1 capital}}{\text{Assets}})$	Core Tier 1 capital includes all permanent share capital, reserves, share premium account, externally-verified interim net profits but excludes intangible assets and investments in own shares.
Change in non-core Tier 1 capital ratio	$100 \times \Delta_2(\frac{\text{Non Core Tier 1 capital}}{\text{Assets}})$	
Change in earning assets to total assets ratio	$100 \times \Delta_2(\frac{\text{Earning assets}}{\text{Total assets}})$	Earning assets are total assets net of cash & balances at central banks, intangible assets and fixed assets.
Change in interest income to earning assets ratio	$100 \times \Delta_2(\frac{\text{Interest income}}{\text{Earning assets}})$	Interest income includes income from interest received and accrued interest that has not yet been collected.
Change in interest expense to earning assets	$100 \times \Delta_2(\frac{\text{Interest expense}}{\text{Earning assets}})$	Interest expense includes interest paid and interest payable that has been accrued, but has not been collected yet.
Change in provisions ratio	$100 \times \Delta_2(\frac{\text{Impairments charge}_{i,t}}{\frac{1}{2}(\text{Assets}_{i,t-1}+\text{Assets}_{i,t-2})})$	

Change in net-interest income to earning assets	$100 \times \Delta_2(\frac{\text{Net interest income}}{\text{Earning assets}})$	Net interest income is the difference between interest income and interest expense.
Change in net operating income ratio	$100 \times \Delta_2(\frac{\text{Post-tax net income}_{i,t}}{\frac{1}{2}(\text{Assets}_{i,t-1}+\text{Assets}_{i,t-2})})$	Post-tax net income is total profits for the financial year up to the reporting date.
Assets growth	$100 \times \frac{\text{Assets}_{i,t}-\text{Assets}_{i,t-2}}{\text{Assets}_{i,t-2}}$	
Tier 1 capital growth	$100 \times \frac{\text{Tier 1 capital}_{i,t}-\text{Tier 1 capital}_{i,t-2}}{\text{Tier 1 capital}_{i,t-2}}$	
Total capital growth	$100 \times \frac{\text{Capital}_{i,t}-\text{Capital}_{i,t-2}}{\text{Capital}_{i,t-2}}$	
Loans growth	$100 \times \frac{\text{Loans}_{i,t}-\text{Loans}_{i,t-2}}{\text{Loans}_{i,t-2}}$	
Deposits growth	$100 \times \frac{\text{Deposits}_{i,t}-\text{Deposits}_{i,t-2}}{\text{Deposits}_{i,t-2}}$	
Risk-weighted assets growth	$100 \times \frac{\text{RWA}_{i,t}-\text{RWA}_{i,t-2}}{\text{RWA}_{i,t-2}}$	
Unsecured lending growth	$100 \times \frac{\text{Unsecured}_{i,t}-\text{Unsecured}_{i,t-2}}{\text{Unsecured}_{i,t-2}}$	Unsecured loans covers all funds lent to counterparties other than credit institutions excluding loans fully secured on residential property.
Residential loans growth	$100 \times \frac{\text{Residential}_{i,t}-\text{Residential}_{i,t-2}}{\text{Residential}_{i,t-2}}$	
Non-performing loans growth	$100 \times \frac{\text{Non-perform}_{i,t}-\text{Non-perform}_{i,t-2}}{\text{Non-perform}_{i,t-2}}$	

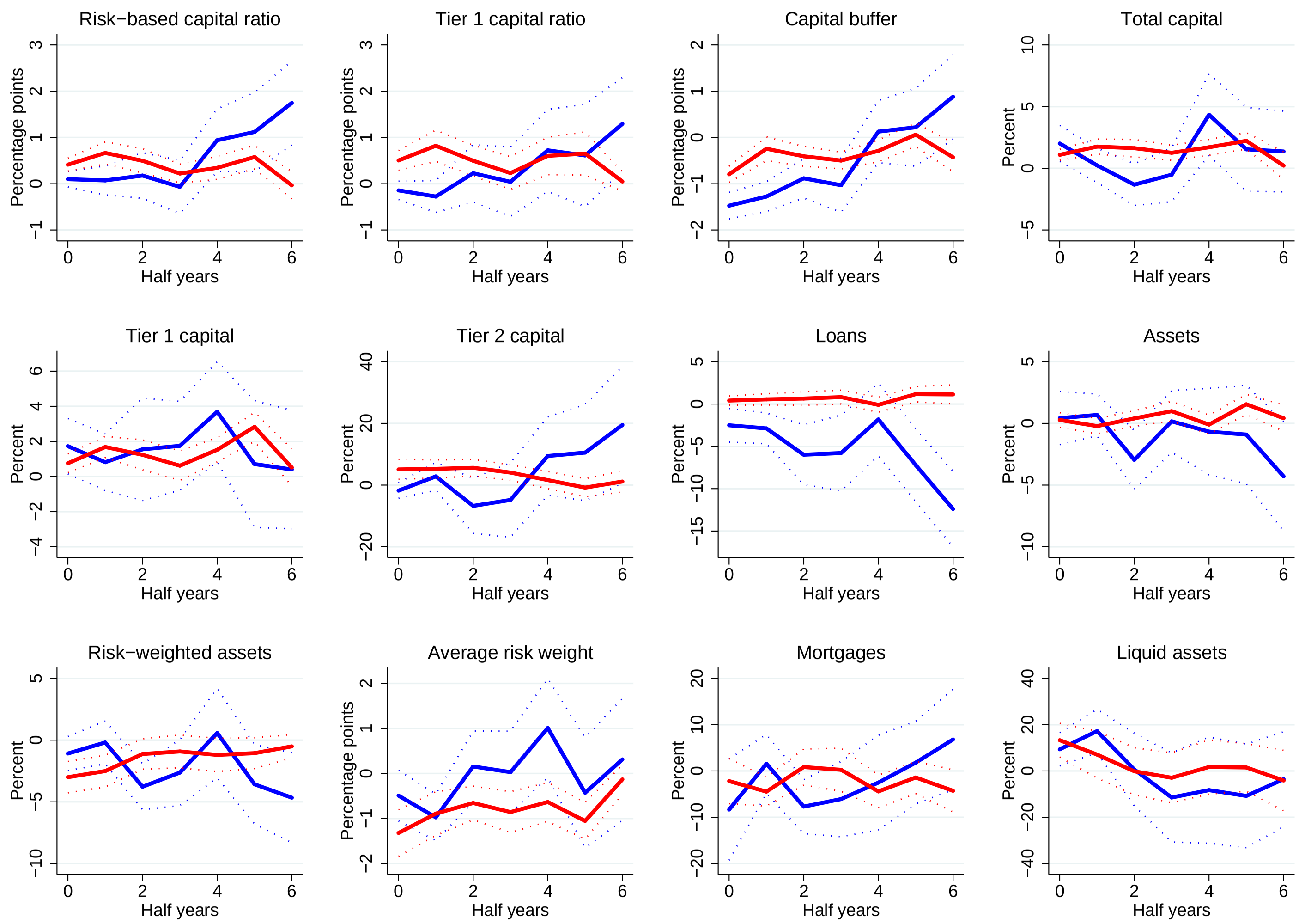
Note: this table provides a list of all variables considered in the lasso regressions of Section 6.1. Δ_2 refers to the annual change in the variable x. Growth rates are all annual. Data is from the Bank of England's HBRD dataset.

Table C.II: Dependent variables used in micro-level analysis

Variable	**Formula**	**Notes**
Risk-based capital ratio	$100 \times \frac{\text{Capital}}{\text{RWA}}$	RWA denotes risk-weighted assets.
Tier 1 capital ratio	$100 \times \frac{\text{Tier 1 capital}}{\text{RWA}}$	
Capital buffer	$100 \times \frac{\text{Capital}-\text{Required capital}}{\text{Required capital}}$	Total required capital is given by the trigger ratio multiplied by total risk-weighted assets.
Average risk weight	$100 \times \frac{\text{RWA}}{\text{Assets}}$	
Liquid assets		Liquid assets here cover highly liquid assets as well as intra-financial deposits and other debt securities. High quality liquid assets are cash and balances at central banks, gilts, Treasury bills and other highly liquid bills.

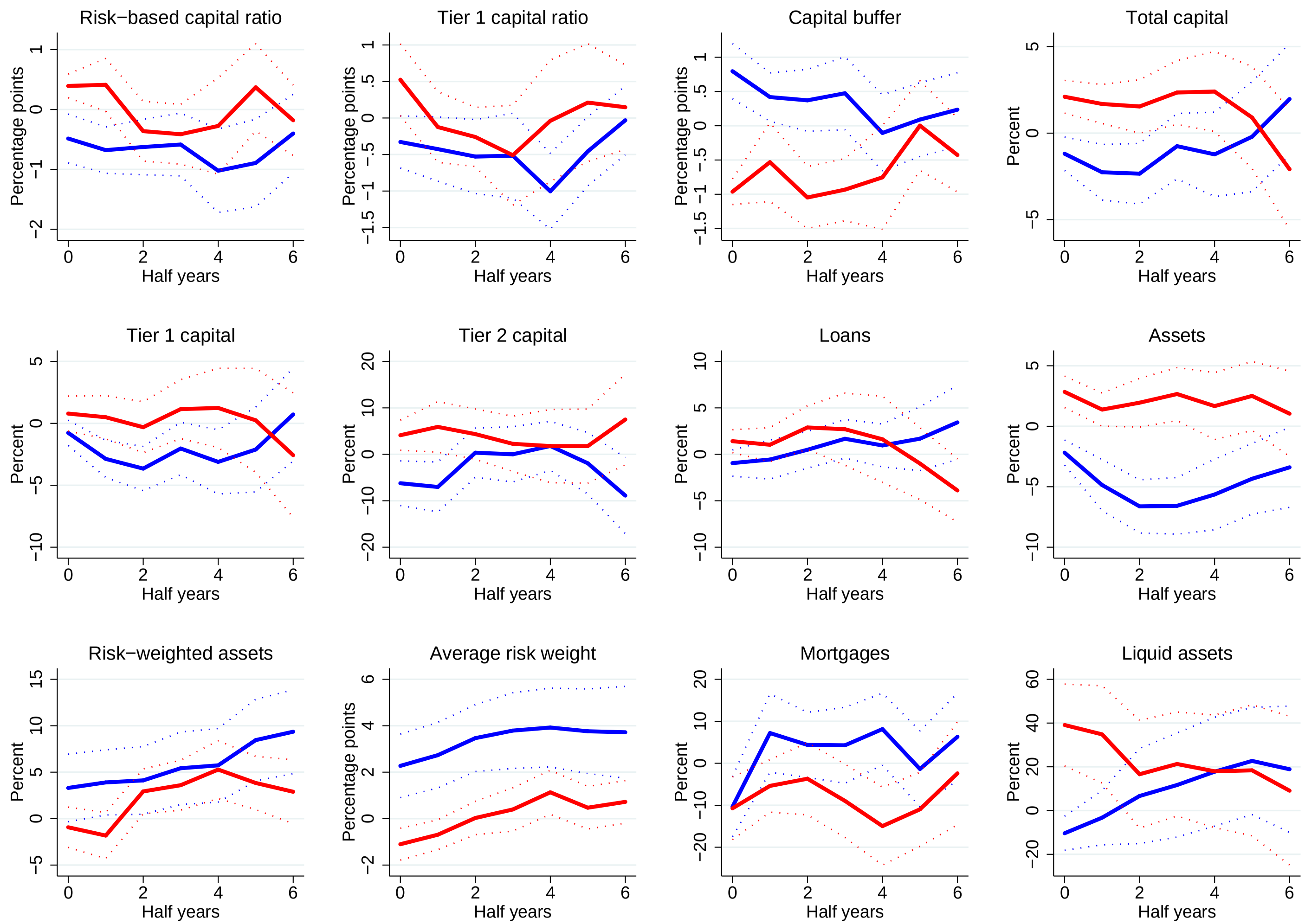
Note: this table provides details on the dependent variables used in the local projections of Equation 1. All data is from the Bank of England's HBRD dataset.

FIGURE C.I: Impulse responses to a 1pp capital requirement increase: pre- vs. post-crisis



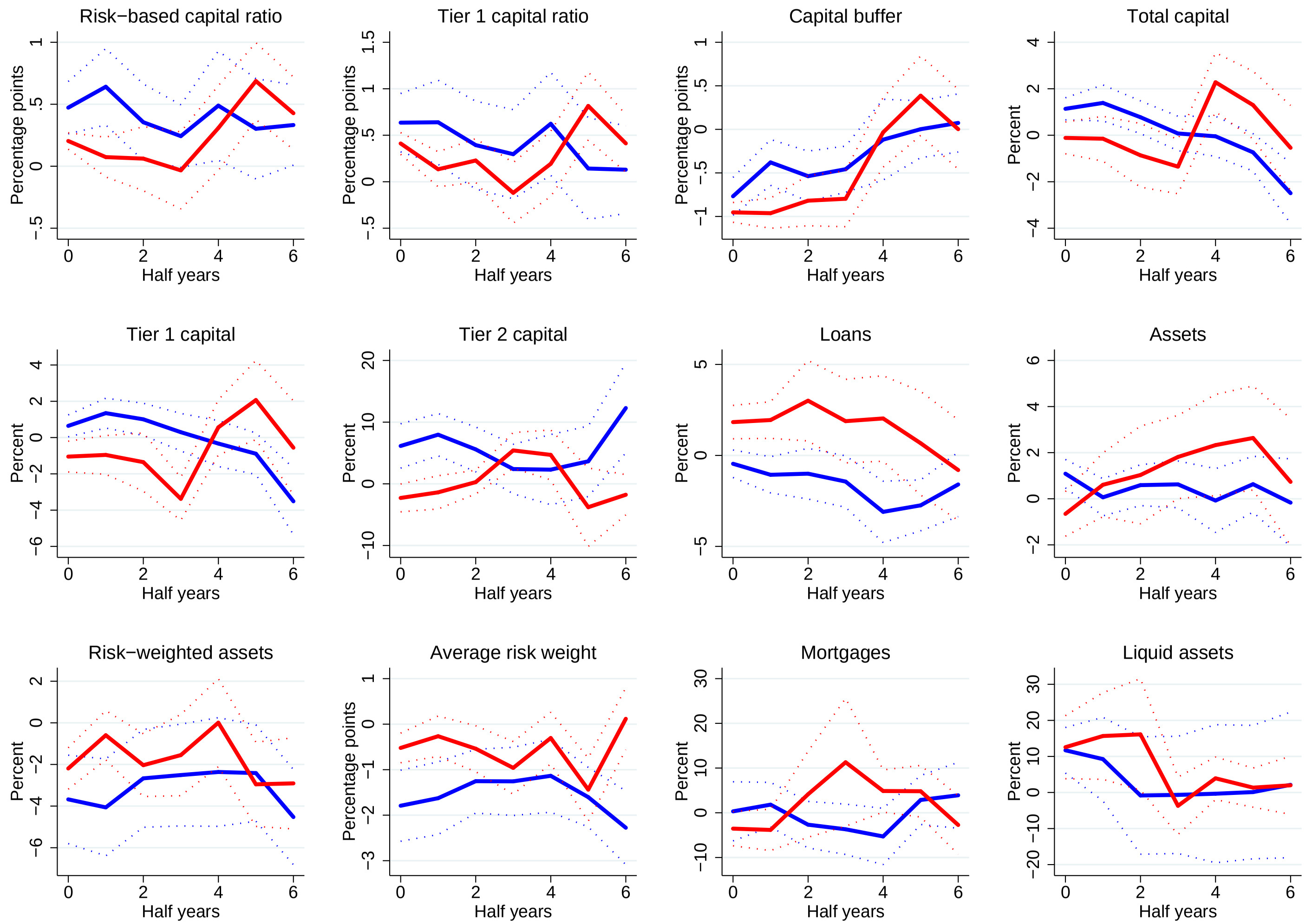
Note: this figure shows the local projection impulse responses for the pre-crisis (in blue) and post-crisis (in red) periods separately following estimation of Equation 1. The impulse responses are for a 1pp increase in capital requirements. Pre-crisis covers dates up to and including 2007H1. Table C.II gives further details on the dependent variables. 68% confidence intervals are shown.

Figure C.II: Impulse responses to a 1pp capital requirement increase vs. a 1pp decrease



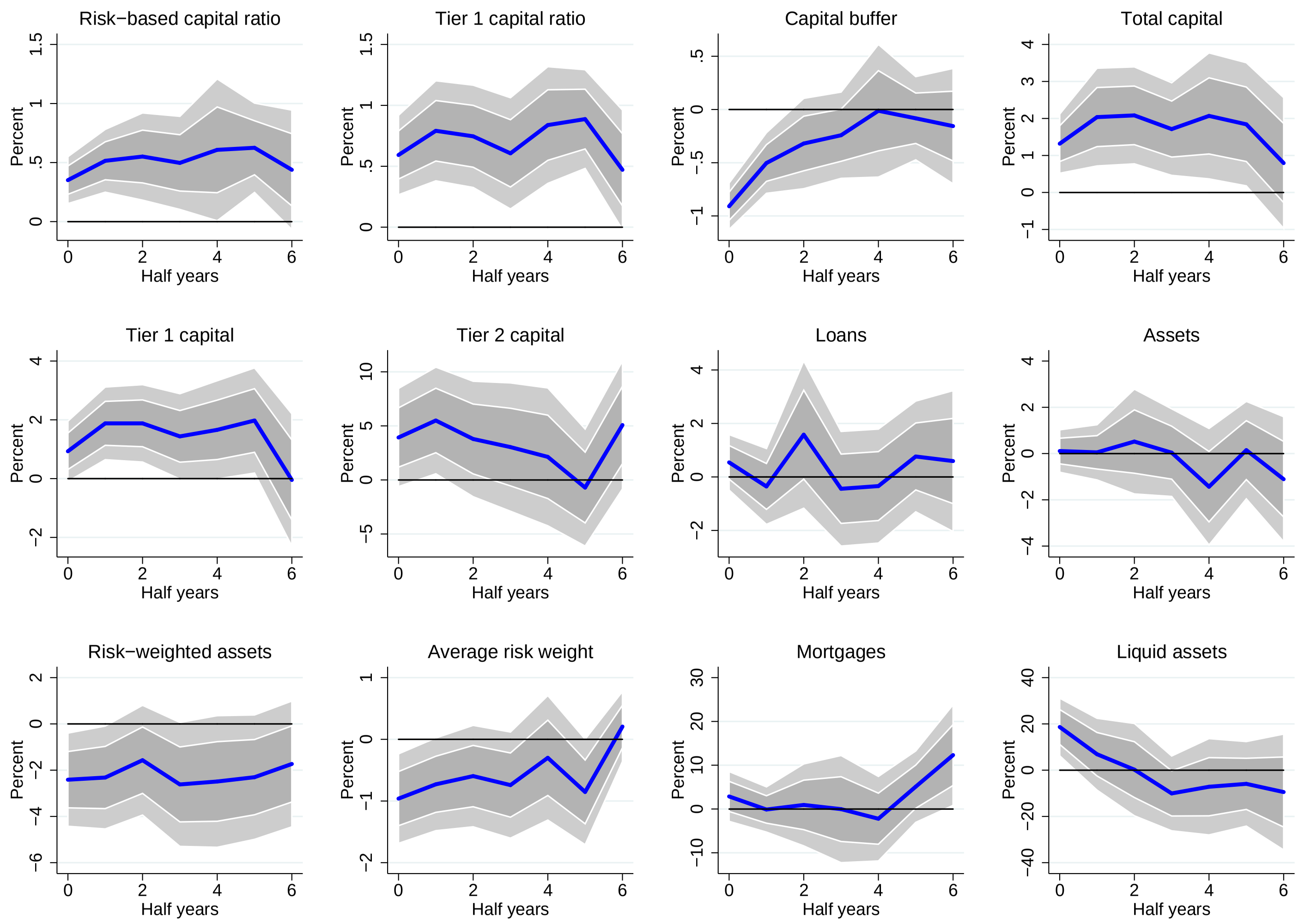
Note: this figure shows the local projection impulse responses separately based on the sign of changes in trigger ratios once bank and time fixed effects have been removed. "Decreases" (in blue) uses only observations with a negative value of this measure and the impulse response is for a 1pp *decrease* in capital requirements. "Increases" (in red) uses only positive values and the impulse response is for a 1pp *increase* in capital requirements. Impulse responses follow estimation of Equation 1 for twelve bank variables. Table C.II gives further details on the dependent variables. 68% confidence intervals are shown.

Figure C.III: Impulse responses to a 1pp capital requirement increase: Small vs. large banks



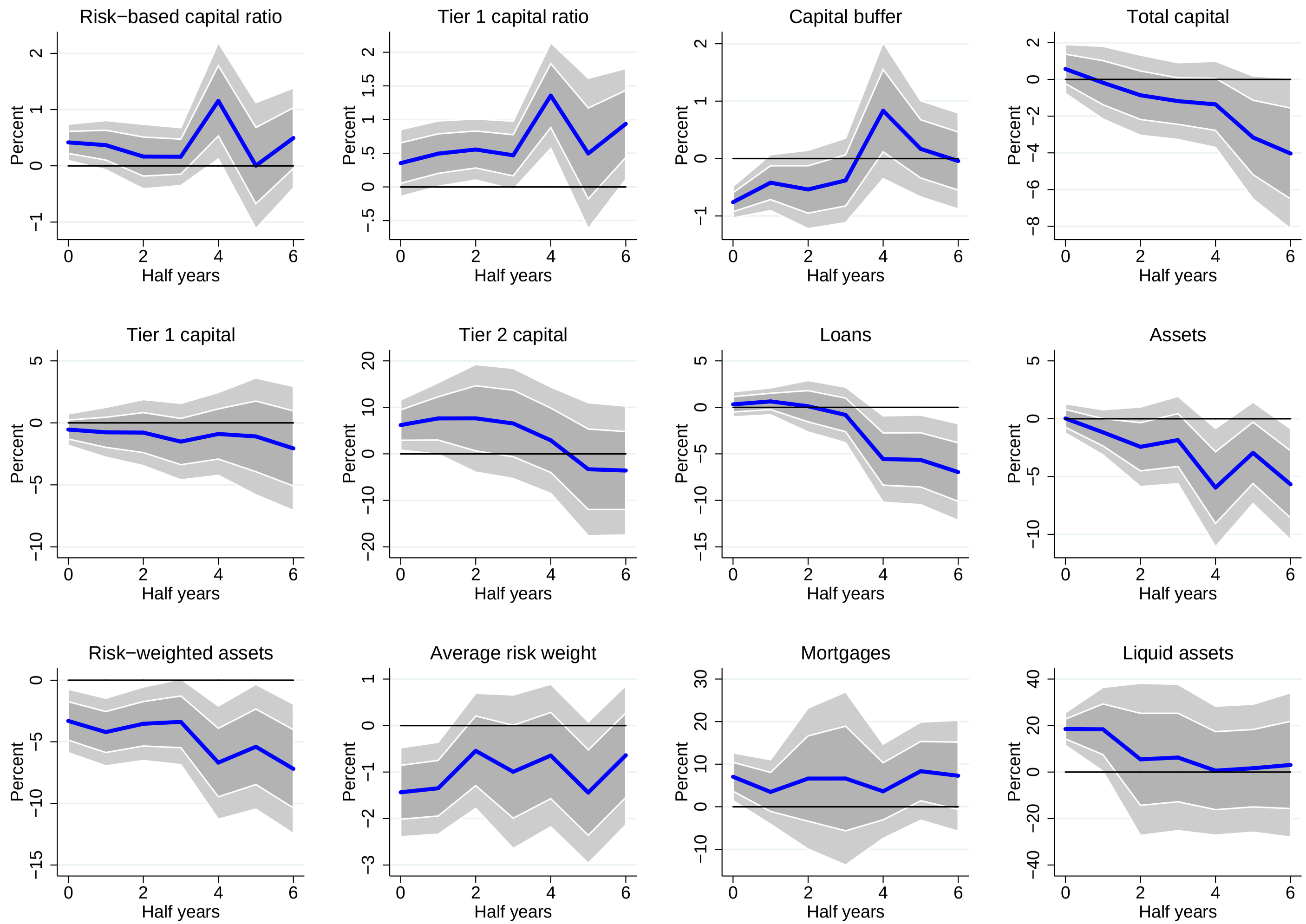
Note: this figure shows the local projection impulse responses to a 1pp capital requirement increase separately based on the size of the bank. "Small banks" (in blue) uses observations where the bank size is below the median of total assets from a given half-year period, while "large banks" (in red) covers banks with total assets above the median value. Impulse responses follow estimation of Equation 1 for twelve bank variables. Table C.II gives further details on the dependent variables. 68% confidence intervals are shown.

FIGURE C.IV: Impulse responses to a 1pp capital requirement increase using only observations for which a requirement change occurred



Note: this figure shows the impulse responses from estimation of Equation 1 for twelve bank variables following a 1pp increase in capital requirements using only those observations for which a change in trigger ratios actually took place. A change has occurred if the half-year change in trigger ratio exceeds 0.1pps in absolute value. Table C.II gives details on the dependent variables. 68% and 90% confidence intervals are shown.

FIGURE C.V: Impulse responses to a 1pp capital requirement increase using only observations for which no change in requirements has occurred in the past 12 months



Note: this figure shows the impulse responses from estimation of Equation 1 for twelve bank variables following a 1pp increase in capital requirements using only those observations where no change in trigger ratios has occurred in the preceding 12 months. A regression of the change in capital ratios on the lasso-selected balance sheet variables (see Column 9 of Table C.VIII) and bank and time fixed effects is used to strip the change in capital ratios of these variables. The residual is used in place of $\Delta trigger_{i,t}$ in Equation 1. A change has occurred if the half-year change in trigger ratio exceeds 0.1pps in absolute value. Table C.II gives details on the dependent variables. 68% and 90% confidence intervals are shown.

TABLE C.III: Summary statistics by time period

	Pre-crisis			Post-crisis			Difference	p-value
	N	Mean	SD	N	Mean	SD		
Trigger ratio	2,630	11.564	2.785	626	11.686	2.691	0.122	0.677
Change in trigger ratio (half year, if change)	295	-0.064	0.728	311	0.149	1.482	0.214	0.003***
Tier 1 risk-based capital ratio	2,630	19.264	16.470	626	19.039	14.322	-0.225	0.895
Total risk-based capital ratio	2,630	21.351	14.710	626	22.185	14.188	0.834	0.617
Capital buffer	2,630	9.721	13.276	626	10.297	13.643	0.576	0.716
Assets growth (half-year)	2,630	3.729	9.006	626	1.072	9.685	-2.658	0.000***
Risk-weighted assets growth (half-year)	2,630	3.436	8.419	626	0.164	10.747	-3.272	0.000***
Average risk weight	2,630	58.573	19.923	626	49.878	20.803	-8.695	0.000***
Liquid asset ratio	2,209	9.691	10.563	620	14.438	10.470	4.747	0.000***
Tier 1 leverage ratio	2,630	10.805	9.574	626	9.484	8.269	-1.321	0.202
Solvency ratio	2,630	177.506	96.493	626	186.866	106.130	9.360	0.441
Loans-to-assets ratio	2,630	51.325	27.711	626	48.994	27.163	-2.331	0.447
Tier 1 capital growth (half-year)	2,630	3.335	7.970	625	2.595	9.702	-0.740	0.103
Total capital growth (half-year)	2,630	3.356	7.772	626	1.751	8.960	-1.605	0.000***
Loans growth (half-year)	2,630	3.286	10.902	626	2.293	12.034	-0.993	0.192
Deposits growth (half-year)	2,614	3.037	16.469	613	2.592	16.816	-0.445	0.594
Unsecured loans growth (half-year)	2,536	3.149	14.616	619	10.454	69.700	7.305	0.011**
Residential loans growth (half-year)	2,101	4.322	27.042	520	40.968	446.971	36.646	0.057*

Note: this table provides summary statistics separately for two time periods. The first three columns show the sample size, mean and standard deviation for the pre-crisis period, defined to be up to and including 2007H1. Columns 4-6 show the corresponding statistics for the post-crisis period, which covers 2007H2-2013H2 inclusive. Column 7 shows the difference in the two means and Column 8 gives the p-value testing equality of means. "Change in trigger ratio (half year, if change)" is the half-year change in the trigger ratio using only those observations where a capital requirement change occurred (a change is coded as having occurred if the half-year change exceeds 0.1pps in absolute value). "Average risk weight" is the ratio between risk-weighted assets and total assets. "Liquid asset ratio" is the ratio of liquid assets to total assets, where liquid assets here are defined as high quality liquid assets as well as credit to other financial institutions, debt securities and equity shares. "Solvency ratio" is the ratio between total regulatory capital and total required capital. "Unsecured loans growth" is the half-year growth of loans not secured on residential property.

Table C.IV: Summary statistics by direction of change in trigger ratio

	Decrease			Increase			Difference	p-value
	N	Mean	SD	N	Mean	SD		
Proportion of post-crisis observations	1,988	0.163	0.369	1,268	0.238	0.426	0.075	0.000***
Proportion of large banks	1,988	0.511	0.500	1,268	0.474	0.500	-0.037	0.049**
Trigger ratio	1,988	11.398	2.804	1,268	11.883	2.682	0.485	0.000***
Change in trigger ratio (half year, if change)	317	-0.729	0.788	289	0.895	0.929	1.624	0.000***
Tier 1 risk-based capital ratio	1,988	18.858	15.961	1,268	19.790	16.248	0.932	0.108
Total risk-based capital ratio	1,988	20.980	14.461	1,268	22.345	14.814	1.366	0.009***
Capital buffer	1,988	9.494	13.212	1,268	10.360	13.545	0.865	0.065*
Assets growth (half-year)	1,988	3.654	9.179	1,268	2.535	9.192	-1.119	0.000***
Risk-weighted assets growth (half-year)	1,988	3.545	8.873	1,268	1.650	9.092	-1.894	0.000***
Average risk weight	1,988	57.079	19.926	1,268	56.624	21.082	-0.455	0.554
Liquid asset ratio	1,685	10.382	10.608	1,144	11.245	10.872	0.863	0.064*
Tier 1 leverage ratio	1,988	10.325	9.201	1,268	10.906	9.574	0.581	0.079*
Solvency ratio	1,988	178.091	98.847	1,268	181.210	97.888	3.119	0.356
Loans-to-assets ratio	1,988	51.592	27.670	1,268	49.754	27.510	-1.838	0.077*
Tier 1 capital growth (half-year)	1,987	3.274	8.028	1,268	3.066	8.793	-0.208	0.537
Total capital growth (half-year)	1,988	3.062	7.816	1,268	3.025	8.377	-0.036	0.913
Loans growth (half-year)	1,988	3.255	11.130	1,268	2.846	11.139	-0.409	0.337
Deposits growth (half-year)	1,976	2.959	16.570	1,251	2.942	16.482	-0.018	0.977
Unsecured loans growth (half-year)	1,911	3.312	17.841	1,244	6.535	48.754	3.223	0.020**
Residential loans growth (half-year)	1,631	9.946	179.687	990	14.305	231.805	4.359	0.613

Note: this table provides summary statistics separately based on the sign of changes in trigger ratios once bank and time fixed effects have been removed. Columns 1-3 and 4-6 show the sample size, mean and standard deviation for decreases and increases respectively. Column 7 shows the difference in the two means and Column 8 gives the p-value testing equality of means. “Proportion of post-crisis observations” gives the proportion of observations in the relevant subgroup that are from the post-crisis period (2007H2 and beyond). “Proportion of large banks” gives the proportion of observations in the subgroup that relate to large banks, where a bank is coded as large if its total assets exceed the median value across all banks in that half year period. “Change in trigger ratio (half year, if change)” is the half-year change in the trigger ratio using only those observations where a capital requirement change occurred (i.e. if the half-year change exceeds 0.1pps in absolute value). “Average risk weight” is the ratio between risk-weighted assets and total assets. “Liquid asset ratio” is the ratio of liquid assets to total assets, where liquid assets here are defined as high quality liquid assets as well as credit to other financial institutions, debt securities and equity shares. “Solvency ratio” is the ratio between total regulatory capital and total required capital. “Unsecured loans growth” is the half-year growth of loans not secured on residential property.

Table C.V: Summary statistics by size of bank

	Small banks			Large banks			Difference	p-value
	N	Mean	SD	N	Mean	SD		
Proportion of post-crisis observations	1,639	0.193	0.395	1,617	0.191	0.393	-0.002	0.942
Trigger ratio	1,639	12.778	2.724	1,617	10.380	2.238	-2.398	0.000***
Change in trigger ratio (half year, if change)	273	0.042	1.370	333	0.048	1.001	0.006	0.937
Tier 1 risk-based capital ratio	1,639	26.373	18.786	1,617	11.971	7.646	-14.402	0.000***
Total risk-based capital ratio	1,639	27.820	17.320	1,617	15.117	6.691	-12.703	0.000***
Capital buffer	1,639	14.865	16.377	1,617	4.730	5.938	-10.135	0.000***
Assets growth (half-year)	1,639	2.850	9.298	1,617	3.592	9.084	0.742	0.097*
Risk-weighted assets growth (half-year)	1,639	2.711	9.541	1,617	2.904	8.428	0.193	0.667
Average risk weight	1,639	57.917	21.755	1,617	55.873	18.840	-2.044	0.475
Liquid asset ratio	1,371	9.342	11.535	1,458	12.037	9.722	2.695	0.059*
Tier 1 leverage ratio	1,639	14.701	10.850	1,617	6.344	4.647	-8.358	0.000***
Solvency ratio	1,639	212.821	120.591	1,617	145.335	49.969	-67.486	0.000***
Loans-to-assets ratio	1,639	47.242	28.785	1,617	54.560	25.875	7.318	0.061*
Tier 1 capital growth (half-year)	1,638	2.466	8.229	1,617	3.929	8.377	1.463	0.000***
Total capital growth (half-year)	1,639	2.496	8.039	1,617	3.606	8.000	1.110	0.002***
Loans growth (half-year)	1,639	3.017	11.978	1,617	3.175	10.209	0.158	0.779
Deposits growth (half-year)	1,614	3.030	17.937	1,613	2.875	15.003	-0.154	0.823
Unsecured loans growth (half-year)	1,609	4.552	36.576	1,546	4.614	30.307	0.062	0.967
Residential loans growth (half-year)	1,204	19.344	294.514	1,417	5.006	30.330	-14.338	0.104

Note: this table provides summary statistics separately based on the size of the bank. A bank is "large" if its total assets exceed the median value across all banks in that half-year period. Columns 1-3 and 4-6 show the sample size, mean and standard deviation for small and large banks respectively. Column 7 shows the difference in the two means and Column 8 gives the p-value testing equality of means. "Proportion of post-crisis observations" gives the proportion of observations in the relevant subgroup that are from the post-crisis period (defined as 2007H2 and beyond). "Change in trigger ratio (half year, if change)" is the half-year change in the trigger ratio using only those observations where a capital requirement change occurred (a change is coded as having occurred if the half-year change exceeds 0.1pps in absolute value). "Average risk weight" is the ratio between risk-weighted assets and total assets. "Liquid asset ratio" is the ratio of liquid assets to total assets, where liquid assets here are defined as high quality liquid assets as well as credit to other financial institutions, debt securities and equity shares. "Solvency ratio" is the ratio between total regulatory capital and total required capital. "Unsecured loans growth" is the half-year growth of loans not secured on residential property.

Table C.VI: Lasso-selected reaction functions for pre- and post-crisis periods

	(1) Pre-crisis	(2) Post-crisis
Constant	-0.00548	-0.10178
	(0.008)	(0.142)
Time fixed effects	Yes	Yes
Bank fixed effects	Yes	Yes
Observations	2630	626
Number of banking groups	193	97
R-squared	0.10	0.05

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors in parentheses. This table shows the lasso estimation following Section 6.1. The first column ("Pre-crisis") uses only observations from before the financial crisis (up to and including 2007H1), while the second column ("Post-crisis") uses from 2007H2 and beyond. The dependent variable is the half-year change in trigger ratio. The variables that appear in the lasso estimation are given in Table C.I. An intercept and bank and time fixed effects are included.

Table C.VII: Lasso-selected reaction functions for small and large banks

	(1) Small	(2) Large
Constant	0.01661	-0.00553
	(0.035)	(0.011)
Time fixed effects	Yes	Yes
Bank fixed effects	Yes	Yes
Observations	1639	1617
Number of banking groups	131	111
R-squared	0.08	0.14

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors in parentheses. This table shows the lasso estimation following Section 6.1. The first column ("Small") uses only observations where the bank size is below the median of total assets from a given half-year period, while the second column ("Large") uses banks with total assets above the median value. The dependent variable is the half-year change in trigger ratio. The variables that appear in the lasso estimation are given in Table C.I. An intercept and bank and time fixed effects are included.

TABLE C.VIII: Robustness checks: lasso-selected reaction functions under different lasso approaches and samples

	(1) Adaptive	(2) Rigorous	(3) EBIC	(4) $K = 5$	(5) $K = 8$	(6) $K = 12$	(7) $K = 15$	(8) If change	(9) No change in 12m
Change in average risk weight									-0.00472
									(0.004)
Non-core Tier 1 capital ratio change									0.00644
									(0.006)
Risk-weighted assets growth									-0.00353**
									(0.001)
Unsecured loans growth									0.00220***
									(0.001)
Non-performing loans growth									0.00002***
									(0.000)
Constant	-0.00361	-0.00361	-0.00361	-0.00361	-0.00361	-0.00361	-0.00361	-0.11748	-0.04976
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.250)	(0.033)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3256	3256	3256	3256	3256	3256	3256	606	1420
Number of banking groups	212	212	212	212	212	212	212	141	112
R-squared	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.16	0.15

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors in parentheses. This table shows the lasso estimation based on different lasso approaches and samples. The dependent variable is the half-year change in trigger ratio. The variables that appear in the lasso estimation are given in Table C.I. An intercept and bank and time fixed effects are included. Columns 1, 2 and 3 show the selected model based on using adaptive lasso (Zou (2006)), clustered rigorous lasso (Belloni et al. (2016)) and the extended Bayesian information criterion (Chen and Chen (2008)) respectively. Columns 4-7 give the selected model using K-fold cross validation for different K. Column 8 uses only observations for which a change in trigger ratio actually took place, where this is determined by whether the half-year change in trigger ratio exceeds 0.1pps in absolute value. Column 9 uses only observations for which no change in trigger ratio has occurred in the previous 12 months. For both Columns 8 and 9, the lasso approach follows the baseline approach of the standard lasso estimator and K-fold cross validation with $K = 10$.