The impact of capital requirements on bank lending

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Abstract

This paper estimates the impact of changing banks' capital requirements on bank capital ratios and bank lending. It exploits changes in bank capital requirements by banking supervisors in the United Kingdom between 1990 and 2011, provides a novel breakdown of the lending effects by economic sector and a timeline over which the effects take place. There are two key results. First, following an increase in capital requirements, banks gradually rebuild the buffers they hold over the regulatory minimum so they remain constant. Second, in the year following an increase in capital requirements, banks, on average, cut (in descending order based on point estimates) loan growth for commercial real estate, for other corporates and for household secured lending. Loan growth mostly recovers within three years. These results may help quantify how changing capital requirements might affect lending in a macroprudential policy framework.

Key words: bank capital, bank lending, regulatory capital requirements, capital buffer, macroprudential policy.

JEL classification: G21, G28.

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1 Introduction

This paper estimates the effect of changing regulatory capital requirements on bank capital and bank lending and the time profile of this adjustment. We contribute to the literature by presenting a holistic view of how banks react to changes in their individual capital requirements - in particular, we estimate how banks adjust their level of capital; over what horizon; what categories of sectoral lending, if any, banks adjust; for how long; and how the adjustment to capital and to lending interact simultaneously.

Having built a rich new data set, we run panel regressions of, first, lending to different parts of the economy on regulatory capital requirements and observed capital ratios, and second, of capital ratios themselves on capital requirements. We use the estimates to build impulse responses that track banks' capital and sectoral lending responses to a permanent one percentage point increase in capital requirements. The shape of the impulse responses is allowed to vary freely both in the short and the long run and takes account of both the direct impact of a change in capital requirements on lending, and the indirect impact via the response of bank capital. Robustness checks are also included to examine differences in responses across time periods, types of banks, and whether capital requirements increase or decrease.

We are able to exploit several unique features of our data set. By using data on confidential bank-specific and time-varying capital requirements set by the Bank of England and the Financial Services Authority (FSA) in the UK between 1990 and 2011, we are able to directly estimate the relationship between changes in capital requirements and individual bank lending behaviour. By examining the response of lending at the sectoral level, we allow both credit supply and credit demand to vary across different sectors of the economy – to our knowledge a novel extension to the existing literature. We also estimate responses at the bank group level (rather than for individual entities) and use a unique measure of 'true' lending flows.

This paper has two key findings on the transmission of capital requirements on to bank lending. The first is that regulatory capital requirements affect the capital ratios held by banks – following an increase in capital requirements, banks gradually rebuild the buffers that they initially held over the regulatory minimum. Second, capital requirements affect lending to the real economy and the effects are heterogeneous across sectors. In the year following an increase in capital requirements, loan growth falls most to the commercial real estate (CRE) sector, followed by other corporate lending and household secured lending. The response of unsecured household lending is not significantly different from zero. Further out, loan growth for most sectors recovers.

Empirical evidence on the link between capital requirements and bank lending, especially with a calibration of the effects at the sectoral level, is of great interest to policymakers. The financial crisis has led to widespread support for the use of capital requirements as a policy tool (for example Yellen (2010) and Hanson *et al* (2011)) and it is important to be able to anticipate the effects of the policy on the real economy. Most jurisdictions around the world are in the process of implementing the countercyclical capital buffer, a key macroprudential policy instrument in the Basel III framework that increases banks' capital requirements when lending is booming and reduces them when lending enters a downturn cycle. In the UK, the Financial Policy Committee has the additional power to set higher capital requirements on lending to particular sectors of the economy (household and corporate lending as well as on intra financial system exposures).[1] While banks' reactions under a macroprudential policy framework may differ to some extent (different signalling and leakage mechanisms may apply), our findings aim to help anticipate how banks may react in their capital levels, their lending response and over what timeline.

The remainder of this paper is structured as follows. In Section 2 we briefly review the existing literature on the effects of capital and capital requirements on bank lending. Section 3 describes our data set and presents summary statistics. We explain our econometric methodology in Section 4. Section 5 presents our results and discusses their implications. Section 6 presents some extensions and robustness checks and Section 7 concludes.

2 Literature

The relationship between bank capital, bank capital requirements and bank lending has been studied from a number of different angles over the past. The academic literature on this subject is rooted in theoretical studies exploring the relationship between a firm's liability structure and its cost of funding. A number of empirical studies followed on the impact of changes in overall capital held by a bank on its lending behaviour. A third strand of literature explores the impact of regulation on bank capital requirements on bank lending. This strand has grown in prominence with the advent of macroprudential policy and the need to assess the relative impact of different policy tools.[2]

Below we review the theoretical and empirical literature with a specific focus on the quantitative effects of capital requirements on the supply of credit and place our study in the context of that literature.

2.1 Early studies

The theoretical benchmark for understanding the impact of a shock to capital funding remains the Modigliani-Miller theorem (Modigliani and Miller (1958)). In the context of the banking sector, the key prediction is that changes in the composition of a bank's liabilities should not affect the overall funding cost, assuming an unchanged level of risk on the asset side of the balance sheet. And without a change in funding costs, there is no reason why a

[1] Bank of England (2014) provides additional information on these tools.

[2] A separate strand of the literature also investigated other aspects of policy such as the 'bank lending channel', or the conditions under which bank lending acts as a channel for monetary policy (Gambacorta and Mistrulli (2004) and Gambacorta and Marques-Ibanez (2011)). We do not review this literature here.

change in the capital ratio of a bank, *ceteris paribus,* should impact on the price or quantity of credit.

There may be various frictions in the market for bank equity, however, which cause changes in capital requirements to have real effects, either in the short or long term. The most often cited long-term friction is the tax deductibility of debt interest payments, which implies an increase to bank's funding costs when capital requirements are raised. Other long-term frictions include debt overhang – Myers (1977) – and asymmetric information – Myers and Majluf (1984). The existence of short-run frictions might depend on how a bank chooses to meet a change in its capital requirements. For example, the costs associated with different ways of adjustment (e.g. cutting dividends versus raising equity) may have implications for funding costs, and consequently, lending decisions.

In this paper, by investigating the effects of a change in bank capital requirements on lending behaviour, we implicitly test the existence of such failures of Modigliani-Miller. Identifying specific frictions is, however, beyond the scope of the paper.

2.2 Impact of changes in capital held on lending

Much of the literature on the impact of capital shocks on bank lending emerged after the US recession in the early 1990s, prompted by questions as to whether the economic situation was exacerbated by capital-constrained banks cutting back on lending – the so-called 'capital crunch' hypothesis. Bernanke and Lown (1991) found that in some regions, a shortage of equity capital – caused in some cases by bank losses on real estate lending – did limit banks' ability to make loans, although it is not clear whether the credit crunch played a major role in worsening the recession.[3] Sharpe (1995) argues that the evidence in favour of a capital crunch is not particularly conclusive. Furfine (2000), in a theoretical model calibrated to the US data, finds instead that capital regulation can explain the decline in loan growth and the rise in bank capital.

Peek and Rosengren (1997) use a natural experiment which allows them to disentangle the impact of a credit supply shock (caused by a reduction in bank capital) from that of credit demand effects. They analyse the US lending operations of the branches and subsidiaries of Japanese banks located in the United States, which suffered a large capital shock after the collapse of equity prices in the late 1980s. They find that a one percentage point fall in the risk-based capital ratio led to an annual fall in loan growth relative to assets of 4 percentage points. An alternative identification strategy exploits individual loan-level data (where availability allows), including matched bank and borrower information. Jimenez *et al* (2013) exploit a matched panel for Spain. They find that lending varies with the capital and liquidity positions of both banks and borrowers as well as with macroeconomic conditions. Albertazzi

[3] This was on account of the low coefficients on the capital ratio, suggesting, for example, that the 1988-90 fall in capital in New England banks explained only 2 to 3 percentage points of that region' s significant decline in lending (total loans fell by 14% between 1990 Q2 and 1991 Q1).

and Marchetti (2010) find similar results when using loan-level data on Italian banks for the period following the collapse of Lehman Brothers.

Heid *et al* (2004), using dynamic panel data techniques on data from German savings banks over the period 1993-2000, find evidence that capital buffers influence decisions on both capital and risk-weighted assets. They find that banks with lower buffers attempt to rebuild them by simultaneously raising capital and lowering risk-weighted assets; banks with larger buffers, instead, raise capital and at the same time *increase* their risk-weighted assets. Stolz and Wedow (2005), however, using an enlarged sample including data for German cooperative banks in addition to savings banks, find that poorly capitalised banks do not decrease risk-weighted assets by more in a downturn than their better capitalised rivals. Similarly, Rime (2001), in a study of Swiss banks during the period 1989-95, finds that banks with a lower capital buffer tend to try to increase their capital ratio, but that they adjust through the level of capital rather than through risk-weighted assets.

Noss and Toffano (2014) study the dynamics of capital and lending at the aggregate level in the United Kingdom, using time series and a VAR identification approach to identify past shocks to banks' capital ratios that – through their associated movement in other variables, including lending growth and corporate bond issuance – might proxy for a shock to bank capital requirements. They find that the level of bank lending might be reduced by as much as 4.5% in response to a 1 percentage point increase in macroprudential capital requirements during an economic boom.

Finally, in a study of banks in over 90 countries, Fonseca *et al* (2010) find that banks with larger capital buffers charge lower interest rates on their lending and pay lower funding costs on their borrowing. They find that this effect is larger in developing countries and during downturns.

2.3 Impact of changes in capital requirements on capital buffers and lending

Our approach falls into the third branch of literature which links directly changes in capital requirements and bank lending behaviour. Recent micro-econometric studies tend to focus on the UK because historically banks have faced different capital requirements over the past two decades and the regulators have adjusted them relatively frequently.

Ediz *et al* (1998), in a study using confidential supervisory data for UK banks, find that, over the period 1989-1995, banks reacted to changes in capital requirements by adjusting the total level of capital rather than by altering lending. Alfon *et al* (2005) estimated that UK banks tend to pass through around 50% of an increase in capital requirements to their capital ratios (and 20% of reductions in capital requirements).

One well-known approach in this area is the partial adjustment model, in which banks adjust over time to their target level of capital. Following the partial adjustment process introduced by Hancock and Wilcox (1994) and using 1996-2007 data, Francis and Osborne (2009) estimate a target capital ratio for each bank in the UK, which is found to depend principally on the individual bank capital requirement (positively) and bank size (negatively). The authors then regress bank lending behaviour on the deviation of the actual capital ratio from target and estimate that a one percentage point increase in capital requirements is found to lead on average to a fall in total lending of 0.8% and a fall in risk-weighted assets of 1.6% after one year.

The Macroeconomic Assessment Group (2010), established by the Financial Stability Board and the Basel Committee on Banking Supervision to assess the impact of higher regulatory capital and liquidity requirements under Basel III, used the methodology in Francis and Osborne (2009) amongst others to estimate across different jurisdictions the impact on lending volumes from a one percentage point increase in the target capital. For an increase in the capital requirement taking place over two years, these estimates ranged from a 0.7% to a 3.6% fall in lending.

A recent paper looking at the impact of capital requirements on bank behaviour is Aiyar *et al* (2014). The aim of their research is to assess whether increases in capital requirements 'leak', in the sense that foreign branches can offset reductions in lending by regulated banks. The paper focusses only on corporate lending and uses a panel data fixed effects framework that regresses loan growth on changes in capital requirements. It finds, first, that the average effect of a 1pp increase in capital requirements is a cumulative reduction in corporate loan growth ranging between 5.7 and 8 percentage points. And second, that 'leakages' of regulation can be considerable – foreign branches operating in the UK offset around a third of the reduction in corporate lending by UK banks.

3 Data

3.1 Data set construction and overview

A strength of our study is the rich panel data set of UK-supervised banks that we have constructed. This data set matches new, high-quality sectoral lending data with unique supervisory data on capital and capital requirements. It fills gaps in existing data sets in a number of ways and improves the precision of our estimates over existing studies.

First, our data contain a large number of changes to bank capital requirements; we can access these confidential data because they were collected under the UK regulatory regime. Second, the sample period (1990-2011) is long enough to measure banks' behaviour in different phases of the economic cycle; to our knowledge it is the longest data series used in UK studies. Third, the lending flows in our data reflect 'true' bank lending behaviour, following considerable efforts by the statistical team at the Bank of England to build a time series that does not include changes in lending stocks due to reasons other than lending. Fourth, the analysis of lending at the sectoral level allows us to build more precise estimates of how changes in policy affect different parts of the economy. Fifth, the data are constructed at the bank group level. In this section we describe the data set and present descriptive statistics.

Our paper makes use of novel data on 'true lending flows' as opposed to 'changes in loan stocks', an important distinction. We retrieve true lending flows such that they reflect only 'transactions', as defined by international standards for economic statistics (in particular the European System of Accounts, ESA 95). Data used in other UK studies on bank lending typically come from the monetary returns collected by the Bank of England (or their equivalent in other countries). These contain detailed information on bank balance sheets, including the stock of loans. However, changes in loan stocks over time also reflect a range of other factors that may potentially contaminate the data. These include write-offs, the effects of securitizations, exchange rate effects, reporting changes, changes to group structures, reclassifications and changes in the values of securities and repos (Equation (1)). For example, we would not want to infer that lending has fallen when a bank securitises some loans (thus removing them from the stock of loans on its balance sheet). Similarly, interpreting write-offs as reductions in lending would be erroneous. Write-offs lead mechanically to a contemporaneous fall in both capital and the loan stock, generating a spurious correlation between the two, regardless of any change in the availability of new credit.

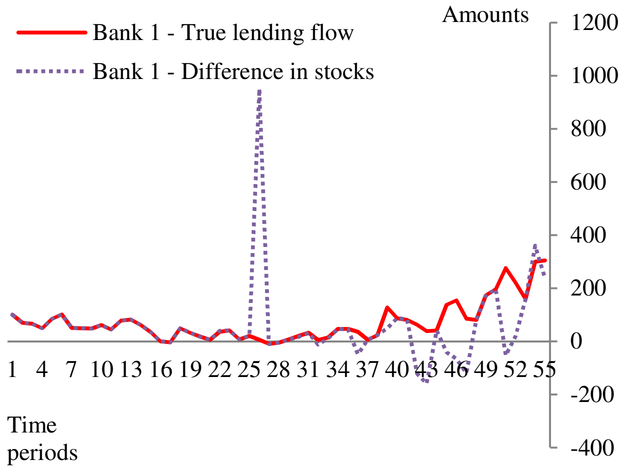
$$stock_t = stock_{t-1} + flow_t - writeoffs_t + exchange\ rate\ adjustment_t + \\ + \Delta securities\ valuation_t + securitization_t + \Delta repo\ valuation_t + \\ + reclassifications_t + other\ adjustments_t \qquad (1)$$

The 'true flows' used in this paper remove this distortion by using additional information from individual banks' monetary returns collected by the Bank of England.[4] Comparing the true flows to differences in stocks reveals substantial differences, as shown in Chart 1 for a bank chosen at random (where x and y values have been rescaled to preserve anonymity). Failing to take account of these issues, and simply using differences in stocks to proxy flows, would lead to biased estimates.

In addition, the 'true' lending flows described above are calculated at the sectoral level as per National Accounts classification. This is in response to the critique by Den Haan *et al* (2007) who argued that empirical studies that consider only total lending can be misleading. The intuition is that if different constituent parts of total lending have different laws of motion, then parameter estimates derived from the sum of the parts will be inaccurate. In our context, for example, we would expect shifts in demand for loans from CRE companies to differ from shifts in demand for unsecured credit from households. We therefore estimate separate equations for loan growth to each sector. This allows us to better control for time variation in macroeconomic factors that impact the demand for different types of lending differently, improving our ability to identify the effect of regulatory capital requirements on lending supply conditions.

[4] Although in principle it would be possible to construct a true flows series from loan-level credit register data used in some of the literature – e.g. Jimenez *et al* (2013) – these loan-level data are not available for the UK. And we are not aware of efforts to build 'true' lending flows in the literature using non-UK data.

Chart 1: Data quality of true lending flows



Note: these data are based on a real bank, but have been rescaled by a constant factor.

We therefore calculate loan growth for each of four sectors: i) secured lending to households; ii) unsecured lending to households; iii) lending to CRE corporations; and iv) lending to non-real estate non-financial corporations. The level of granularity to distinguish between (iii) and (iv) is, however, only available since 1997. Table 1 shows each sector's share in the stock of loans to the real economy at the end of 2011[5] and the Basel I and II regulatory risk weights applied to each.

Table 1: Size and regulatory risk weights of each lending sector

	Share of outstanding stock of loans[6]	Basel I risk weights	Basel II (standardised) risk weights[7]
Secured lending to households	65%	50%	35% for LTV≤ 80% Up to 45% for LTV> 100%
Unsecured lending to households	8%	100%	100%
Lending to CRE corporations	11%	100%	100%
Lending to non-real estate corporations	16%	100%	20%-100% dependent on credit rating

[5] 'Real economy' lending is defined as the stock of loans to households and PNFCs.

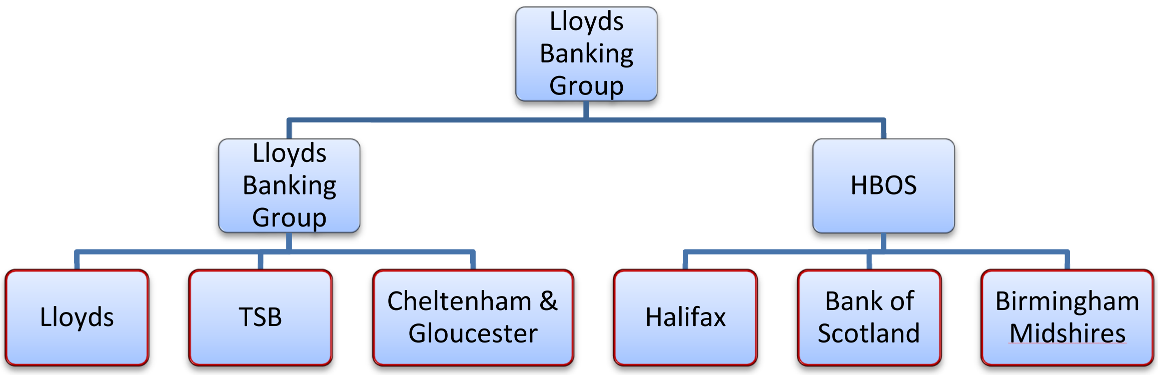
[6] Stock of loans includes only the four "real economy" sectors included in Table 1. Lending to other financial companies is not included in this paper, given it is less directly linked to economic activity and is typically very volatile.

[7] Note, however, that larger UK banks implemented the Internal Ratings Based (IRB) approach rather than Standardised approach under Basel II.

Another feature of our data set is that it is constructed at the banking group level, on what is termed a 'consolidated' basis, as opposed to an unconsolidated (individual entity) basis. The reason is that both lending and capital decisions are, in our view, likely to be determined at the group level. Banking groups typically report their lending strategy and results at the group level. And the capital resources and constraints of a subsidiary are likely to influence decisions at a group level. The importance of group cash flow and capital resources is highlighted in Houston *et al* (1997); Ashcraft (2008) shows that parent groups act as a source of strength in times of distress by providing liquidity and capital.

For this reason we use consolidated returns for bank capital resources and capital requirements and we 'quasi-consolidated' the lending data from the monetary returns by summing across constituent parts of a banking group. [8] This means that, using Lloyds Banking Group as an example in Figure 1, we analyse the capital and lending figures for the group and not for its six sub-entities separately (Lloyds, TSB, Cheltenham and Gloucester, Halifax, Bank of Scotland, Birmingham Midshires).

Figure 1: Example group structure for Lloyds Banking Group



In case of mergers and acquisitions, frequent in our sample, we do not consolidate pre-merger entities as if they were one unit before the merger happens. Rather, after a merger we end the time series for that group and we establish a new banking unit after the mergers. We also exclude at least a quarter of data after any merger, as balance sheets can exhibit peculiar behaviour around the time of mergers and acquisitions.[9] This treatment makes our sample less balanced, but we see this as preferable to backwards engineering a synthetic aggregate of

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[8] It is worth noting that the two data sources differ in scope, even after the monetary returns are quasi-consolidated. The monetary returns capture the UK operations of a wide set of UK and foreign banks, whereas the regulatory returns capture the UK and foreign operations of UK-*regulated* banking groups. And 'quasi-consolidated' data do not strip out intra-group activity that is not included in truly consolidated data.

[9] For example, following Lloyds acquisition of HBOS (Halifax Bank of Scotland) in January 2009, both the Lloyds Banking Group and HBOS series terminate in 2008Q4 and a new series for Lloyds Banking Group commences in 2009Q3, excluding 2009Q1 and Q2.

merged banks, as is sometimes done in the literature. Any other data-cleaning procedure is detailed in Appendix 1.

3.2 The UK regulatory capital framework – 1990-2011

Under both the Basel Accord and European Directives on capital requirements, a bank's total capital ratio (total capital / risk-weighted assets) had to be at least 8% of risk-weighted assets (RWA). On top of the hard floor of 8%, UK regulators have, for over two decades, set bank-specific minimum capital requirements – the source of variation that we exploit in this paper. A breach of this bank-specific minimum capital requirement leads to enhanced supervisory action and can ultimately result in the loss of a firm's banking licence.

These bank-specific minimum capital requirements were formerly known as 'trigger ratios' and were set by the Bank of England.[10]After 1997, the FSA inherited the setting of trigger ratios from the Bank, and following the Financial Services and Markets Act of 2001, trigger ratios were renamed Individual Capital Guidance (ICG). After Basel II was introduced in 2008, the setting of individual capital requirements became part of the Pillar 2 'supervisory review' process conducted by the FSA and subsequently the Prudential Regulation Authority (PRA).

Trigger ratios were initially set by the Bank of England to compensate for the uniformity and simplicity of the Basel capital adequacy framework and varied across banks according to the risk profile of the firms, the bank's size and position in chosen markets, as well as the future outlook in those markets. It also allowed the regulator to capture other risks not covered in the Basel capital adequacy framework, such as operational, legal, and interest rate risks, as well as factors such as the quality of risk management, the quality of internal control and accounting systems and plans for future developments of the business. In the UK Pillar 2 individual capital requirements are now divided into parts – a Pillar 2A requirement, to cover risks either not captured, or not fully captured by Pillar 1, and a Pillar 2B requirement, intended to cover risks to which a firm might become exposed over a forward-looking planning horizon (e.g. due to changes in the economic environment).

As noted by Francis and Osborne (2009), individual ratios were typically reviewed every 18-36 months, resulting in significant time-series as well as cross-sectional variation. This is illustrated in Chart 2 below.

3.3 Descriptive statistics

Our panel data set includes data from 1990 Q1 until 2011 Q3 and is thus a sufficiently long sample to capture all stages of the business cycle. We have included all banks, both active and inactive, which have reported total UK assets greater than Θ5 billion at any time

[10] The Bank of England also used to set 'target ratios', typically set 50-100bps above the trigger to avoid an accidental breach.

since 1990 Q1.[11] As a result, our panel contains 53 banking groups, each with an average of 30 quarters of data.[12]

Table 2 presents summary statistics for the capital and lending variables used in this analysis: for each bank, the minimum capital requirement, its changes, the observed capital ratio, household secured loan growth, household unsecured loan growth, CRE loan growth and the growth in loans to non-CRE companies.[13]

Table 2: Summary statistics[14]

	Obs	Mean	Std Dev	10% percentile	90% percentile
Minimum capital requirement (% of RWA)	1,590	9.93	1.79	8.00	11.99
Changes in minimum capital requirement (percentage point)	1,590	0.03	0.32	-0.03	0.05
Changes in minimum capital requirement (percentage point) – *excluding [-0.1; 0.1] range*	253	0.17	0.79	-0.53	0.95
Capital ratio (% of RWA)	1,549	15.82	8.27	10.65	22.57
Secured loan growth (%, q on q)	1,298	0.50	5.78	-6.43	5.54
Unsecured loan growth (%, q on q)	1,459	1.62	5.27	-2.78	7.38
Non-CRE companies loan growth (%, q on q)	857	1.55	8.78	-9.44	11.96
CRE loan growth (%, q on q)	897	2.49	10.73	-7.26	12.51

Chart 2 shows the variation in the minimum capital requirements over the sample period. Excluding negligible changes (smaller than 0.1 in absolute value), there were 253 changes in the sample, with a slight prevalence of increases (143 occurrences) over decreases (110 occurrences). The changes were mostly between 0 and 1 percentage point in absolute value (Chart 3). Chart 4 illustrates how capital buffers (i.e. the difference between the overall capital ratio and the minimum requirement) broadly fell across banks in the decade leading up to the crisis, before being rebuilt in the last two years of the sample.

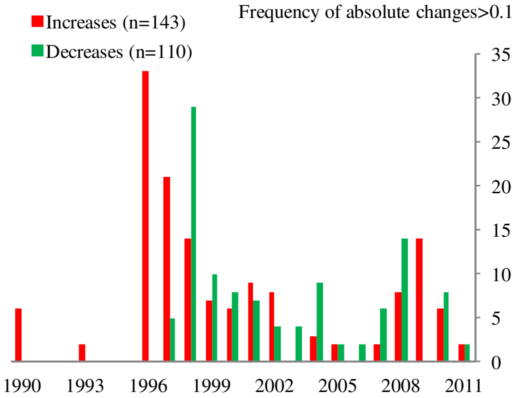
[11] An inactive bank is defined as one which has dropped out of the sample by 2011Q3, perhaps because it was taken over.

[12] The panel includes the lending operations of foreign-owned banks with UK resident subsidiaries.

[13] Throughout this paper, minimum capital requirements and actual capital ratios are defined in 'total capital' terms. In other words, the numerator of these ratios includes all types of regulatory capital.

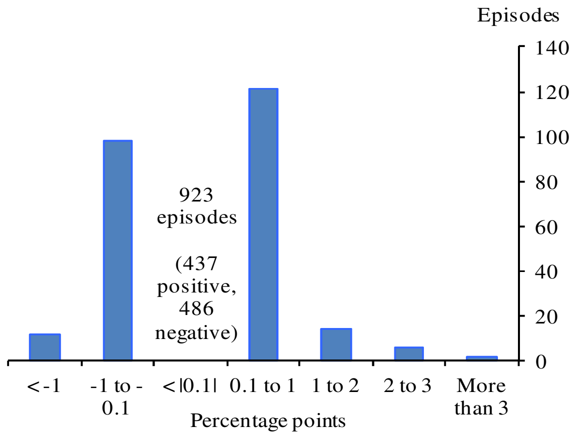
[14] For further detail on some of the variables see Appendix 2.

Chart 2: Variation in minimum capital requirements



Sources: Bank of England and FSA

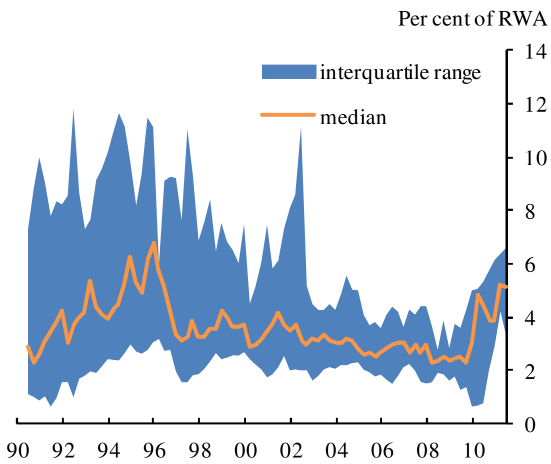
Chart 3: Magnitude of changes in minimum capital requirements



Sources: Bank of England and FSA

Note: Excludes when minimum capital requirements did not change. In total there are 253 episodes of changes larger than 0.1 in absolute value

Chart 4: Capital buffer



Sources: Bank of England and FSA

4 Methodology

To determine how banks typically react to a change in capital requirements, we estimate dynamic panel equations for bank capital and loan growth for each sector as follows:

$$cap_{it} = \alpha_1 + \sum_{k=1}^{4} \gamma_{1k} cap_{i,t-k} + \sum_{k=1}^{4} \delta_{1k} trig_{i,t-k} + \theta_i^{cap} + \vartheta_t^{cap} + \epsilon_{it} \qquad (2)$$

$$\dot{loan}_{it} = \alpha_2 + \sum_{k=1}^{2} \beta_{2k} \dot{loan}_{i,t-k} + \\ + \sum_{k=1}^{2} \gamma_{2k} cap_{i,t-k} + \sum_{k=1}^{2} \delta_{2k} trig_{i,t-k} + \varphi_2 M_{it-1} + \theta_i^{loan} + \vartheta_t^{loan} + \varepsilon_{it} \quad (3)$$

Where cap_{it} is actual capital as a fraction of risk-weighted assets for bank *i* in quarter *t*; $trig_{i,t}$ is the capital requirement (trigger ratio) set by the regulator; $\dot{loan}_{it}$ is quarterly loan growth based on the true flows as described in Section 3.1; and $M_{i,t-1}$ is a vector of bank-specific micro controls that might affect lending, namely proportion of Tier 1 capital and the leverage ratio. These variables describe the *quality* of capital resources, in addition to the quantity captured by *trig*[15]. θ and ϑ denote bank and time fixed effects respectively, and ε and ϵ are error terms.

The number of lags in each equation was determined in a general to specific procedure, testing down from four lags and restricting the number of lags for capital and the capital requirement to be the same both within and across equations. The lagged dependent variables have the effect of mopping up residual autocorrelation. Equation (2) is estimated on the full sample (with the only restriction that secured and PNFC loan growth were non-missing) while equation (3) is estimated for each different type of lending (secured, unsecured, CRE and non-CRE corporates). Each equation is estimated separately – the correlation between error terms in the lending and capital equation is small and insignificantly different from zero for each lending equation, which allows us to treat the responses similarly to as if estimated as a system.

We use fixed effects for banks and for quarterly time periods. Banks' fixed effects control for unobserved heterogeneity at the bank level; for example, systematic differences in business models, domicile or size. Quarterly time fixed effects control for macroeconomic factors - including demand-side effects that are common to all banks at a given point in time; for example, if all banks' lending flows were lower in a certain period because of weak demand, the time dummies would capture this by taking a lower value in that particular period. Estimating each sectoral lending equation separately, with separate time fixed effects, allows for different patterns of demand in each sector, improving our ability to identify the impact of regulatory capital requirements on bank lending supply conditions.[16]

Nonetheless, we do not claim watertight identification: even with fixed effects at the sectoral level, demand effects might confound our estimates if, for example, capital requirements were increased for banks mainly operating in a particular area of the UK at the

[15] Aside from these controls for the quality of capital resources, we also experimented with additional controls for liquidity and prospects for capital resources. These were excluded from the final specification and they did not improve the fit of the model or materially influence the main results.

[16] It should be noted that the time fixed effects will also control for any supply-side effects that are common to all banks and that these fixed effects cannot control for demand-side effects within a given sector that are specific to a given bank.

same time as demand fell in that particular area.[17] In order to better identify credit demand, loan-level data would be required. But such data does not exist for the UK, which is, to our knowledge, the only jurisdiction for which there are data on time-varying bank-specific capital requirements. Researchers are therefore presented with a trade-off: either they are able to control for credit demand by using loan-level data containing borrower characteristics (for example, using the Spanish credit register as in Jimenez et al (2013)) but have to use proxies for changes in capital requirements; or have the latter but not the former, as in our case.

The results are broadly robust to explicitly including macro controls (GDP and inflation) instead of time fixed effects, but the latter are better at soaking up all factors common to banks at any point in time without the need to model them.

The presence of both lagged dependent variables and fixed effects causes a well-known bias (Nickell, 1981). But as our sample contains a relatively large number of time periods and only a moderate cross-section – relative to many panel datasets – using panel data techniques with fixed effects remains preferable to Generalised Method of Moments (GMM). That is because the lagged dependent variable bias declines as the number of time period increases, and our estimates will be consistent as long as there is no autocorrelation of the error terms. Judson and Owen (1999) suggest using standard fixed effects estimation rather than GMM in unbalanced panels when T is large, which applies to our data, where the average bank has a time series of 30 quarters. Standard errors are robust and clustered at the bank level.

An additional issue arises because methods that involve pooling data (such as the fixed effects estimator and other panel methods) assume homogeneity of coefficients across banks. Pesaran and Smith (1995) suggest using the Mean Group estimator to tackle this issue. However, the highly unbalanced nature of our panel (which is partly a result of the treatment of mergers and acquisitions, see Section 3.1) means that this estimator is not appropriate. That is because the Mean Group estimator would give a very large weight to coefficients estimated for banks with only few observations, leading to very high standard errors. We instead relax the homogeneity assumption by investigating in Section 6 the impact of capital requirements for different types of banks.

Central estimates for impulse responses are calculated using the point estimates from equations (2) and (3), while the calculation of confidence intervals follows the methodology used in Beyer and Farmer (2006). Specifically, we take 2,500 draws from the joint normal distribution with mean and variance-covariance matrices given by the vectors of point estimates and variance-covariance matrices estimated from equations (2) and (3). The impulse responses are ranked within each quarter and the upper and lower bounds of the confidence

[17] In addition, it is possible that supervisors tended to increase capital requirements when they were concerned about asset quality. In that case, the estimated effect might be rather large as it would capture the bank's lending response to both higher capital requirements and concerns about asset quality. However, Aiyar, Calomiris and Wieladek (2014) provide some evidence that this is unlikely to be the case. They find that changes in write-offs (lagged, present and future) cannot predict changes in capital requirements and note from Francis and Osborne (2009) that the UK discretionary regime was meant to 'fill gaps in the early Basel I system, which did not consider risks related to variation in interest rates, or legal, reputational and operational risks'.

interval are given by the 16th and 84th percentiles, as is typical in the macro literature following Sims and Zha (1999).

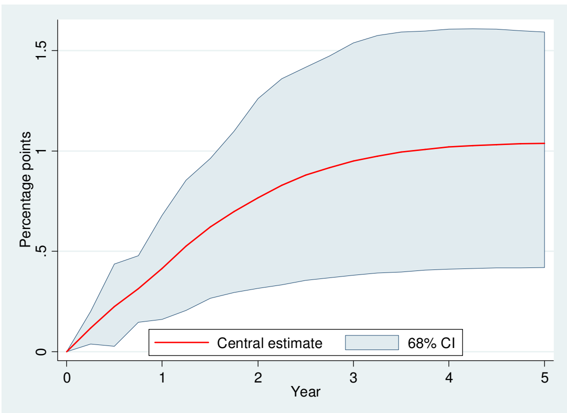
5 Results

This section presents the main results on how banks adjust their capital and lending following a change in capital requirements, based on the estimates from the two dynamic panel equations (2) and (3). Tables 3 and 4 present the capital ratio and sectoral lending responses to a one percentage point permanent increase in capital requirements, while Charts 5 to 9 illustrate the dynamics of the adjustment process. A full set of coefficient estimates for all of our preferred specifications can be found in Appendix 3.

5.1 The impact of capital requirements on capital ratios

Equation (2) examines how a bank's capital ratio behaves in relation to its own capital requirement and past capital ratios. Banks are found to actively adjust their total capital held in response to changes in capital requirement, as opposed to letting the capital buffer adjust in equal and offsetting measure. This result is in line with other studies that use UK data, such as Alfon *et al* (2005) and Francis and Osborne (2009).

Chart 5: Capital ratio impulse response



Note: Capital ratio impulse response following a permanent one percentage point increase in the capital requirement at time 0.

Table 3: Capital ratio response to 1pp increase in capital requirements

	Response to a 1pp increase in capital requirements
Change in observed capital ratio after 1 year	0.41*
(68% CI)	[0.16 : 0.68]
Change in observed capital ratio after 3 years	0.95*
(68% CI)	[0.38 : 1.54]
Dependent variable (no. of lags)	4
R^2	0.95
Observations	1,095

Note: * denotes significantly different from zero using the 68% confidence interval. The regression includes bank and quarterly time fixed effects.

Our central estimate suggests that, following a one percentage point permanent increase in capital requirements, banks start to increase their capital ratio (potentially via a combination of raising new capital, retaining profits or reducing assets) (Chart 5). After one year, banks have increased their capital ratio by 0.4pp and after 3 years by 0.9pp (Table 3); the initial buffer is fully restored in less than four years. Our central estimate suggests that the adjustment settles just above 1pp, indicating that banks increase their capital ratio broadly one for one in response to an increase in capital requirements. The confidence interval in Chart 5 highlights the considerable uncertainty around this central estimate, but suggests that the positive response of actual bank capital ratios to an increase in regulatory requirements is statistically significant.

5.2 The impact of capital requirements and capital ratios on sectoral loan growth

Equation 3 examines how banks' sectoral loan growth is related to their individual capital requirement, observed capital ratio and past loan growth. Table 4 presents the results from the regressions

Table 4: Loan growth response to 1pp increase in capital requirements

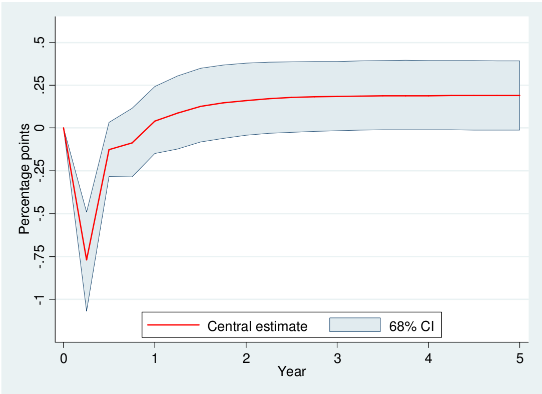
	(1) Household secured loan growth	(2) Household unsecured loan growth	(3) CRE loan growth	(4) Non-CRE corporates' loan growth
Peak impact on loan growth quarterly rate (pp)	-0.77*	-0.19*	-4.04*	-2.05*
(68% CI)	[-1.07 : -0.49]	[-0.37 : -0.01]	[-5.56 : -2.63]	[-3.51 : -0.73]
(quarter)	1	5	1	1
Impact on loan growth rate over year 1 (annual, pp)	-0.94*	-0.68	-8.07*	-3.86*
(68% CI)	[-1.69 : -0.20]	[-1.43 : 0.03]	[-10.46 : -5.70]	[-6.05 : -1.54]
Long-run impact on quarterly loan growth (at end-year 3, pp)	0.18	-0.16	-1.33*	-0.67
(68% CI)	[-0.01 : 0.39]	[-0.36 : 0.04]	[-1.85 : -0.77]	[-1.34 : 0.05]
Dependent variable (no. of lags)	2	2	2	2
R^2	0.21	0.12	0.10	0.09
Observations	1,143	1,358	809	760

Note: * denotes significantly different from zero using the 68% confidence interval. The effect over year 1 is calculated as the sum of the four quarterly effects. All regressions include bank and quarterly time fixed effects.

a) Household secured lending

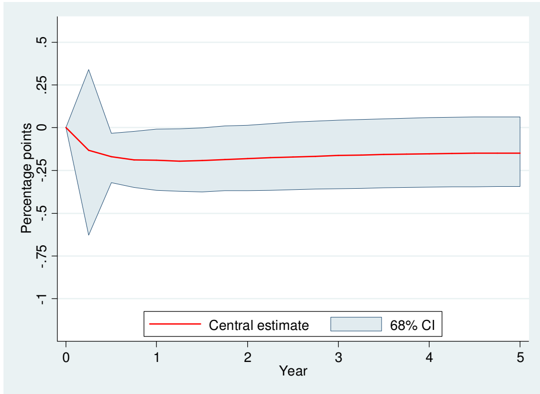
An increase in capital requirements is associated with a temporary reduction in secured loan growth, which on our central estimate lasts less than a year (Chart 6). In the first quarter following the regulatory change, household secured loan growth falls sharply, with a peak impact of reducing the quarterly growth rate by 0.8pp. The cumulative effect over the first year is -0.9pp (Table 4). After the first year, as the bank accumulates capital towards restoring its buffer, loan growth returns to its previous rate.

Chart 6: Secured loan growth impulse response



Note: Secured loan growth impulse response following a permanent one percentage point increase in the capital requirement at time 0.

Chart 7: Unsecured loan growth impulse response



Note: Unsecured loan growth impulse response following a permanent one percentage point increase in the capital requirement at time 0.

b) Household unsecured lending

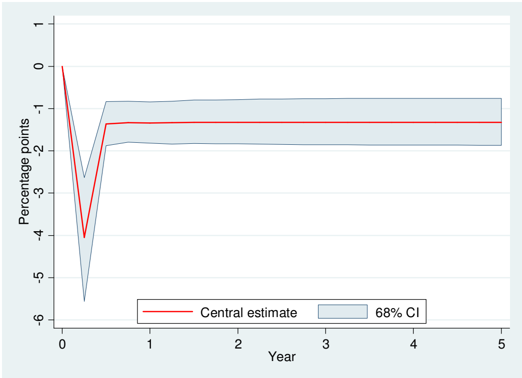
Household unsecured loan growth exhibits a much shallower response to an increase in capital requirements (Chart 7). Our central estimate is for a trough fall in quarterly loan growth of 0.2pp after five quarters and a reduction in the loan growth rate of 0.7pp cumulatively after a year and 0.2pp in the long run. Of these effects, only the trough fall in the 5th quarter is significantly below zero.

c) CRE lending

Turning to corporate lending, we analyse lending to CRE and other industries separately.[18] Following an increase in capital requirements, CRE lending falls sharply (Chart 8). The results suggest that, faced with a 1pp increase in capital requirements, banks reduce CRE loan growth by around 4pp after a quarter; this effect is statistically significant. The cumulative fall in loan growth over the first year is 8pp. Further, our main specification suggests a permanent effect, with quarterly loan growth remaining 1.3pp (around 5pp annualised) lower. However, as noted in Sections 6.1 and 6.3 respectively, this result is not significant before the crisis and may be driven by decreases in banks' capital requirements.

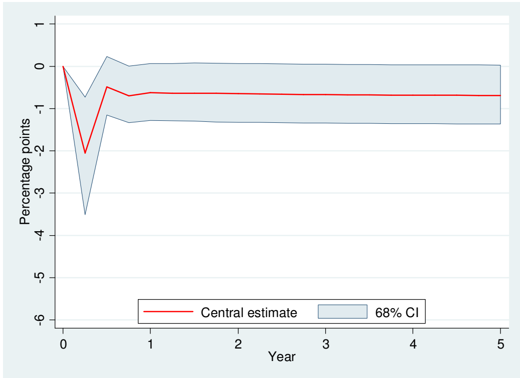
[18] We have also estimated the model for lending to all PNFCs over the longer time series, but there appears to be little effect from changes in capital requirements to lending. This may not be surprising as the equations for all PNFCs rely on lending data from a range of diverse industries with potentially different responses.

Chart 8: CRE loan growth impulse response



Note: CRE loan growth impulse response following a permanent one percentage point increase in the capital requirement at time 0.

Chart 9: Non-CRE corporates' loan growth impulse response



Note: Non-CRE corporates' loan growth impulse response following a permanent one percentage point increase in the capital requirement at time 0.

d) Non-CRE corporate lending

Following an increase in capital requirements, loan growth to companies in other industries[19] also falls significantly; the magnitude of this effect is more muted than for real estate but stronger than for secured lending (Chart 9). The central estimate suggests a trough fall of 2.1pp in quarterly loan growth in the first quarter and a 3.9pp fall in annual growth by the end of the first year. There is no significant long-run impact.

5.3 Discussion

Taking the above together, there are two key findings. First, regulatory capital requirements affect the capital ratios held by banks – following an increase in capital requirements, banks gradually rebuild the buffers that they initially held above the regulatory minimum. Second, capital requirements affect lending with heterogeneous responses in different sectors of the economy – in the year following an increase in capital requirements, banks cut (in descending order based on point estimates) loan growth for CRE, other corporates and household secured lending. The response of unsecured household lending is shallower and insignificant over the first year as a whole. Loan growth mostly recovers within 3 years. The exception is CRE lending for which there is evidence of a long-run effect. But, given this result may be driven by episodes in which capital requirements were falling, and is not significant before the crisis, we refrain from placing too much weight on it.[20]

These results are not directly comparable to those of other studies. But a very rough comparison to Macroeconomic Assessment Group (2010), Aiyar *et al* (2014) and Noss and

[19] Non-CRE corporates' loan growth is calculated as corporate lending less CRE lending. Due to differences in definitions, especially related to a reclassification of housing associations, this measure tends to be less precise than that of CRE lending.

[20] During the crisis, lenders suffered large losses on their CRE and other corporate loan books (in absolute terms and relative to household lending). The CRE lending market is a particularly cyclical industry; this may be one explanation for our result, discussed in Section 6.4, that CRE lending is more sensitive to capital requirements when there is a negative output gap.

Toffano (2014) can be made by calculating the cumulative effect over three years[21] for each sector in our study, and then calculating the total effect using the sector shares from Table A as weights. On that measure, we find that the impact of a 1pp increase in the capital requirement on loan volumes is about -3.5%, compared to between -0.7 and -3.6% in Macroeconomic Assessment Group (2010), -5.7 to -8.0% in Aiyar *et al* (2014) and -4.5% in Noss and Toffano (2014). The finding of Noss and Toffano (2014) that the effect is larger for lending to corporates (and in particular CRE) than to households is consistent with our point estimates in Table D, and could be one explanation why Aiyar *et al* (2014) – who look at corporate lending only – find a relatively large effect.

Our results reflect how, on average, individual banks respond to a change in their own confidential and microprudential capital requirements. Whilst our findings may contain some insights into how macroprudential policy will impact bank behaviour, there are likely to be a number of differences in the macroeconomic implications. First, the extent of 'leakages' – where entities not subject to a change in capital requirements step in to pick up any slack in lending left by banks subject to the change – may be different when capital requirements are changed for a large set of banks simultaneously.

Second, a macroprudential policy regime may have different implications for the way in which banks adjust their capital ratios to a regulatory chance. Following a system-wide increase in capital requirements, banks might not restore their capital buffers in the same way as in the past because they may not be able to all simultaneously acquire capital. On the other hand, a synchronised regulatory change may diminish any signalling problems associated with raising additional capital. Also, during the transition to higher global regulatory standards, increasing capital requirements might augment rather than reduce lending for initially undercapitalised banks if confidence effects boost their resilience and capacity to lend. Furthermore, macroprudential regulators are often required to consider the wider implications of changing capital requirements, which could include any adverse impact on lending – for example, while the FPC's primary objective is to protect and enhance the resilience of the UK financial system, it also has a secondary objective to support the economic policy of the Government.

Third, macroprudential capital requirements are intended to operate within a more systematic and transparent framework than their microprudential counterpart. For example, we might expect banks to react in a different way to anticipated and unanticipated changes in their capital requirements, such that a transparent and well-communicated macroprudential regime may induce different bank behaviour, to the extent that future policy decisions are more easily anticipated.

As a result, our study cannot be read as a like-for-like map of how changing capital requirements likely affects bank capital and lending in a macroprudential framework; but it is

[21] The effect in Macroeconomic Assessment Group (2010) is for the 18th quarter of simulation; Aiyar, Calomiris and Wieladek (2014) assumes that changes in capital requirements have no effect on loan growth after four quarters; while Noss and Toffano (2014) estimate the effect over 4 years. The studies also differ along other dimensions.

a useful guide to how banks have adjusted their capital ratios and lending structure on average in response to past microprudential supervisory actions.

6 Extensions and robustness checks

We investigate the robustness of our results along five dimensions: a) influence of the financial crisis; b) heterogeneity by size of bank; c) asymmetry between increases and decreases in capital requirements; d) business cycle variation in banks' responses; and e) heterogeneity by size of the capital buffer. We note that the results in this section are based on preliminary analysis intended to provide some idea of where our main results come from and interrogate their robustness, rather than on fully developed econometric exercises. More details on the methodology and charts of impulse responses are available in Appendix 4.

6.1 Influence of the financial crisis

To examine the influence of the financial crisis on our results, we re-estimate equations (2) and (3) excluding data from 2008 onwards. The results on capital and on secured lending are generally robust to this exclusion. In the case of unsecured lending, lending responds more negatively when estimated on data until 2007 only. One possible explanation is that, while unsecured loan growth responded to changes in individual banks' capital requirements before 2007, after 2007 it became less responsive because of pricing and demand effects. First, when setting loan quantities and prices, it is plausible that the increase in riskiness of unsecured borrowers after 2007 and the cost to cover potential credit losses from defaulting borrowers dwarfed any reaction to changes in capital requirements. Button *et al* (2010) show that the cost of capital is only a very small fraction of the overall price of an unsecured loan.[22] Second, demand for unsecured credit may have increased since the start of the crisis as households used relatively more unsecured credit to smooth banks' restrictions in secured credit.

Effects on corporate lending, on the contrary, become more muted if the crisis years are excluded. For CRE lending, the long-run growth rate effect is not present when estimating only until 2007. And for lending to other corporations, there are no significant effects before the crisis.

6.2 Heterogeneity by size of bank

The results do appear to differ between large and small banks, although the degree is dependent on how 'large' is defined – whether by the size of total assets, real economy lending or sectoral lending; whether by size of loan stocks or by growth rates; whether the definition is dynamic, such that a bank can change from large to small or vice versa over time, or static. This dependence limits inference on how large and small banks behave differently. But to give an example, when defining large banks in a given quarter as the top 50% in terms

[22] Specifically, in decomposing the pricing of unsecured loans, Button, Pezzini and Rossiter (2010) estimated that a 10% unsecured loan rate (for a Θ10,000 personal loan) would comprise around 450bps to cover credit losses and only 80bps to cover the cost of setting aside regulatory capital.

of total assets in that quarter, small banks generally appear to be the main driver of the results on lending. Large banks tend to exhibit less negative effects initially, with the exception of lending to non-CRE corporates. That may be because large, most likely international, banking groups have more flexibility as to how they raise and allocate capital than small banks. As such, they may be able to better insulate themselves from, or respond to, regulatory actions

6.3 Asymmetry between increases and decreases in capital requirements

The results presented in Section 5 assume that banks react symmetrically, i.e. banks' responses to an increase in capital requirements are the mirror image of their response to a decrease. Initial analysis suggests this is not the case for all sectors empirically. The strong initial reaction for CRE and household secured lending in particular appear to be driven by *increases* rather than decreases in capital requirements: CRE lending is lowered by 4.7pp in response to a 1pp increase in capital requirements, but increased only 2.1pp in response to a similar decrease in capital requirements, and secured lending to households is not significantly affected by reductions in capital requirements. This result chimes with Elliott *et al* (2013), who find, in a study of macroprudential policy actions – taking place throughout the twentieth century and spanning a wide range of instruments, including interest rate controls, reserve requirements and capital requirements – in the United States, a policy tightening has a larger effect on lending than an easing. On the other hand, the long-run growth effect for lending to the CRE sector appears to be driven by *reductions* in banks' capital requirements. The effects for lending to the non-CRE corporate sector are more symmetrical.

6.4 Business cycle variation in banks' responses

Banks' response to changes in capital requirements might vary over time with the business cycle. Here we examine the extent to which responses vary between times when the output gap is positive or zero ('good' times), and when the output gap is negative ('bad' times).[23]

We find that banks tend to cut corporate lending more when the output gap is below zero; CRE lending is initially reduced by 4.6pp and non-CRE corporate lending by 3.9pp in that case. In contrast, CRE lending is reduced by only 1.8pp and non-CRE corporate lending by 0.5pp when the output gap is positive, and these effects are insignificant. For unsecured lending to households, the immediate reaction is also stronger when the output gap is negative, but loan growth returns more quickly to normal in that case. Finally, the initial response is similar for household secured lending, but the response for times when the output gap is positive exhibits a somewhat puzzling positive response in the long run.

[23] An alternative would be to split the sample based on whether GDP growth was above or below its long-run trend, but a dummy based on this split is too volatile for the exercise to be meaningful.

6.5 Heterogeneity by size of the capital buffer

It is possible that banks with capital buffers close to zero are particularly sensitive to changes in the regulatory capital requirement. We examine this hypothesis by estimating impulse responses for banks with lagged capital buffers above and below 1.5 per cent. Based on our central estimates, we do indeed find that the initial lending reaction is stronger for banks with smaller capital buffers, with the exception of CRE lending where the initial reaction is similar. But further out, CRE and non-CRE corporate loan growth remains subdued for banks with large buffers while it recovers completely for banks with small buffers. Lending to households recovers for both sets of banks.

7 Conclusion

Our results suggest that changes in capital requirements affect both capital and lending. In response to an increase in capital requirements, banks gradually increase their capital ratios to restore their original buffers held above the regulatory minimum. Banks also reduce loan growth – in the year following an increase in capital requirements, banks cut (in descending order based on point estimates) loan growth for CRE, other corporates and household secured lending. The response of unsecured household lending is shallower and not significant over the first year as a whole. Loan growth mostly returns to normal within 3 years. Finally, initial analysis suggests that banks' responses differ depending on bank size, capital buffers held, the business cycle, and the direction of the change in capital requirements.

These results reflect how, on average, individual banks responded in the past to a change in their own confidential and microprudential capital requirements. As such, they cannot be used to directly infer the macroeconomic effects of macroprudential policy.[24] But as long as we lack empirical evidence on the effectiveness of the new policy tools, and to the extent that there will be similarities in the way in which banks respond to changes in capital requirements, our results will contain some quantitative insights into how changing capital requirements in a macroprudential framework might affect lending.

[24] See Section 5.3 for a fuller discussion.

Appendices

Appendix 1 – Data cleaning

Mergers and acquisitions: As discussed in Section 3, we have split bank groups in order to take account of mergers and acquisitions. As reported balance sheet characteristics often display volatility around the time of a merger or acquisition, we excluded the quarter associated with the merger, following Kashyap and Stein (2000). However, even then jumps in the data remained common around M&A activity, so in some cases we excluded additional quarters based on judgement.

Start-ups and wind-downs: Similarly, data jumps are often present when a bank is starting up or winding down. Therefore we eliminated the first four quarters in a start-up and the last four quarters in a wind-down.

Outliers: We removed banks with less than five time-series observations. We also removed outliers by excluding some observations at the top and bottom of the range of each variable, cutting the top and bottom 1-5% depending on the noisiness of the original data.

Appendix 2 – Key variable (Table A1)

Variable	Definition	Source	Notes
$\dot{loan}_{i,t,hhsec}$	Quarterly growth of secured loans to households	Monetary returns	Uses true flow of M4Lx
$\dot{loan}_{i,t,hhunsec}$	Quarterly growth of unsecured loans to households	Monetary returns	Uses true flow of M4Lx
$\dot{loan}_{i,t,pnfccre}$	Quarterly growth of loans to CRE private non-financial corporations	Monetary returns	Uses true flow of M4Lx
$\dot{loan}_{i,t,pnfcnoncre}$	Quarterly growth of loans to non real estate private non-financial corporations	Monetary returns	Uses true flow of M4Lx
$cap_{i,t}$	Published total capital ratio (includes all types of qualifying regulatory capital)	Regulatory returns	% of risk-weighted assets
$trig_{i,t}$	Trigger requirement: $\frac{\text{Required total capital resources}}{\text{Risk weighted assets}}$	Regulatory returns	% of risk-weighted assets
$tier1_{i,t}$	Tier 1 capital ratio: $\frac{\text{Tier 1 capital}}{\text{Total regulatory capital}}$	Regulatory returns	
$lev_{i,t}$	Leverage: $\frac{\text{Total assets}}{\text{Tier 1 capital}}$	Regulatory returns	

Appendix 3 – Full table of results

Table A2 shows the full set of coefficient estimates for our main specifications described in equations (2) and (3). These estimates are used to generate the impulse responses shown in Section 5 using the method explained in Section 4.

Table A2: Results for main loan growth and capital equations

	(1) Secured loan growth	(2) Unsecured loan growth	(3) CRE loan growth	(4) Non-CRE corporates' loan growth	(5) Capital
Trigger ratio (-1)	-0.771**	-0.131	-4.044**	-2.055	0.118
	(0.304)	(0.509)	(1.517)	(1.434)	(0.082)
Trigger ratio (-2)	0.838**	-0.015	2.685*	1.391	-0.088
	(0.310)	(0.546)	(1.351)	(1.658)	(0.094)
Trigger ratio (-3)					0.058
					(0.307)
Trigger ratio (-4)					-0.009
					(0.180)
Capital (-1)	0.132	-0.149	0.203	0.348	1.673***
	(0.181)	(0.133)	(0.516)	(0.298)	(0.056)
Capital (-2)	-0.096	0.180	-0.168	-0.385	-1.294***
	(0.184)	(0.121)	(0.479)	(0.340)	(0.142)
Capital (-3)					0.878***
					(0.186)
Capital (-4)					-0.333***
					(0.096)
Tier 1 ratio (-1)	0.026	0.019	-0.006	0.003	
	(0.021)	(0.016)	(0.055)	(0.037)	
Leverage ratio (-1)	0.040	0.027	0.175	-0.166	
	(0.046)	(0.040)	(0.140)	(0.107)	
Dependent variable (-1)	0.269***	0.051	0.006	-0.066	
	(0.053)	(0.059)	(0.041)	(0.065)	
Dependent variable (-2)	0.180***	0.172***	-0.002	0.051	
	(0.046)	(0.040)	(0.065)	(0.054)	
Time and bank fixed effects	yes	yes	yes	yes	yes
Constant	-3.900	-1.171	5.871	12.496	0.754*
	(3.164)	(2.639)	(10.941)	(10.617)	(0.415)
Observations	1,143	1,358	809	760	1,095
R-squared	0.213	0.120	0.103	0.090	0.945
Number of banks	41	50	37	39	41

Note: Fixed effects regressions of loan growth and capital. Capital is actual capital as a fraction of risk-weighted assets. Trigger ratio is the capital requirement set by the regulator. Tier 1 ratio is the ratio of tier 1 capital to total regulatory capital. Fisher-type panel unit root tests suggest no unit roots for any of the variables used. Robust standard errors in parentheses. ***p<0.01, ** p<0.05, * p<0.10.

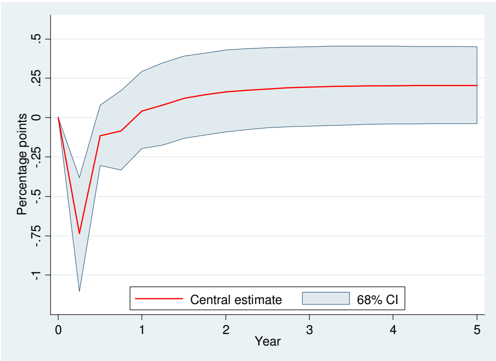
Appendix 4 – Extensions and robustness checks

a) Influence of the financial crisis

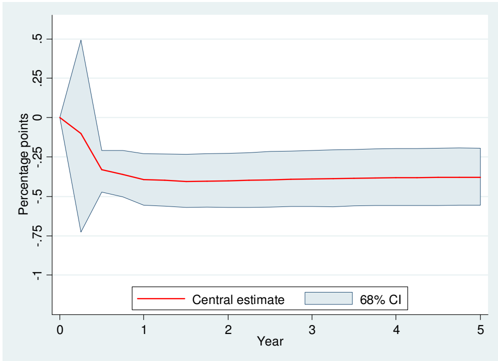
The robustness check for the effect of the financial crisis explained in Section 6.1 was conducted by estimating equations (2) and (3) for a subsample containing data from before the crisis (up to end 2007). Chart A1 shows the impulse responses for lending to each sector for the pre-crisis period.

Chart A1: Loan growth impulse responses pre-crisis

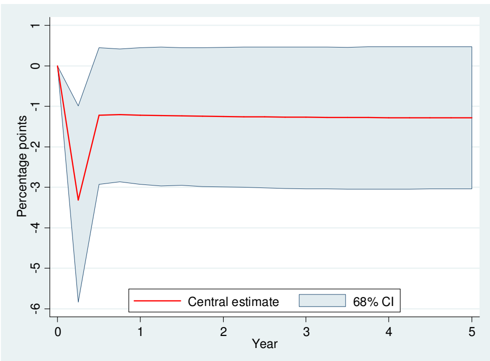
Secured



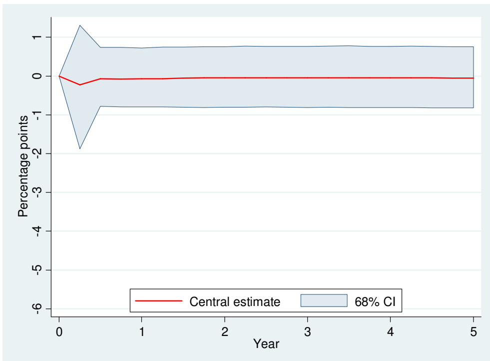
Unsecured



CRE



Non-CRE corporates



Loan growth impulse responses following a permanent one percentage point increase in the capital requirement at time 0.

To test formally for the existence of a structural break during the crisis, we created interaction variables between a crisis dummy (taking value 1 from 2008 Q1 onwards) and the regressors in the lending equations. We then estimated the regressions with the additional interaction variables and tested for their joint significance. According to this test, there is a structural break if the interaction variables are jointly significant. The results are presented in Table A3.

Our tests suggest that the null hypothesis is not rejected for secured and non-CRE corporate lending, so that there was no structural break in those series. On the other hand, we find structural breaks for household unsecured and CRE lending.

Table A3: F-tests for structural break during the crisis

	F	Prob>F	Structural break?
Secured lending	1.21	0.3181	No
Unsecured lending	2.89	0.0102	Yes
CRE lending	4.54	0.0007	Yes
Non-CRE corporate lending	1.20	0.3236	No

F-tests for structural break during the crisis. The null hypothesis is that there was no structural break.

b) Heterogeneity by size of bank

To examine whether there is heterogeneity in the lending and capital results depending on bank size (as discussed in Section 6.2), we estimated the following dynamic panel equations:

$$cap_{it} = \alpha_1 + \sum_{k=1}^{4} \gamma_{11k} cap_{i,t-k} + \sum_{k=1}^{4} \delta_{11k} trig_{i,t-k} + \vartheta_1 size_{i,t-1} + \sum_{k=1}^{4} \gamma_{12k} cap_{i,t-k} * size_{i,t-1} + \sum_{k=1}^{4} \delta_{12k} trig_{i,t-k} * size_{i,t-1} + \theta_{11i} + \theta_{12t} + \epsilon_{it} \quad (A1)$$

$$\dot{loan}_{it} = \alpha_2 + \sum_{k=1}^{2} \beta_{21k} \dot{loan}_{i,t-k} + \sum_{k=1}^{2} \gamma_{21k} cap_{i,t-k} + \sum_{k=1}^{2} \delta_{21k} trig_{i,t-k} + \varphi_{21} M_{it-1} + \vartheta_2 size_{i,t-1} + \sum_{k=1}^{2} \beta_{22k} \dot{loan}_{i,t-k} * size_{i,t-1} + \sum_{k=1}^{2} \gamma_{22k} cap_{i,t-k} * size_{i,t-1} + \sum_{k=1}^{2} \delta_{22k} trig_{i,t-k} * size_{i,t-1} + \varphi_{22} M_{it-1} * size_{i,t-1} + \theta_{21i} + \theta_{22t} + \varepsilon_{it} \quad (A2)$$

where $size_{i,t-1}$ is a dummy variable taking the value 1 if a bank is 'large' and 0 if a bank is 'small'. We use lagged size to avoid any potential endogeneity problems. Our preferred definition of 'large' is a bank that is in the top 50% of the distribution at that point in time in terms of total assets. We also tried an array of alternative definitions of bank size, based on the stock of lending to the real economy (households and corporates) and the stock of lending to each sector. We also considered the growth rate of these variables rather than the stock to test for differential effects for fast-growing banks. We also estimated our equations separately for subsamples of small and large banks. As discussed in Section 6.2, the results are sensitive to the choice of definition. Chart A2 shows the impulse responses of lending in each sector for small and large banks using our preferred definition of 'large'.

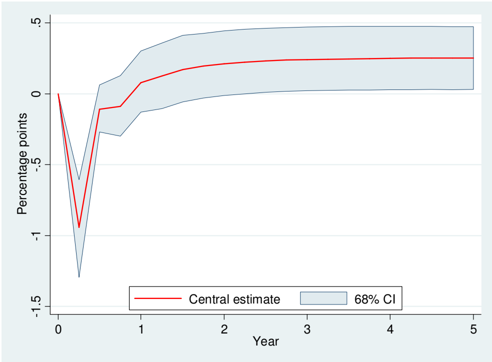
c) Asymmetry between increases and decreases in capital requirements

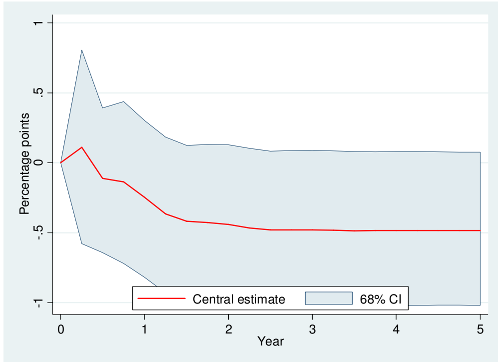
As a preliminary attempt to see whether banks respond symmetrically to increases and decreases in capital requirements, we estimate equations (2) and (3) for subsamples containing episodes of increases and decreases in capital requirements separately. We define an increase in capital requirements episode as one in which the capital requirement has 'net' increased over the previous year (ie $trig_{i,t-1} - trig_{i,t-5} \geq 0$, so offsetting changes do not count). Column 1 in Chart A3 shows the impulse responses of lending in each sector following an increase in capital requirements, and column 2 shows the impulse responses following a decrease in capital requirements.

Chart A2: Loan growth impulse responses for small and large banks

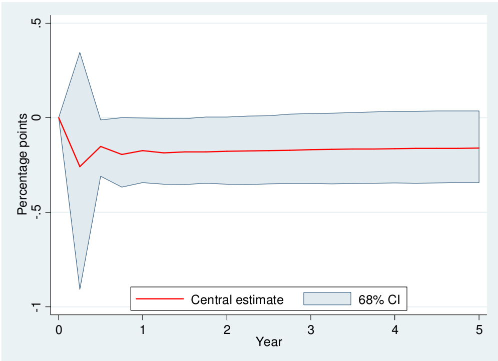
Small banks	Large banks

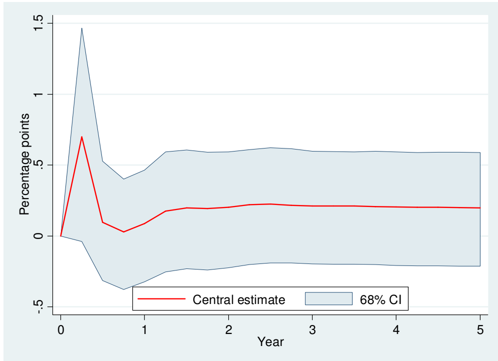
Household secured



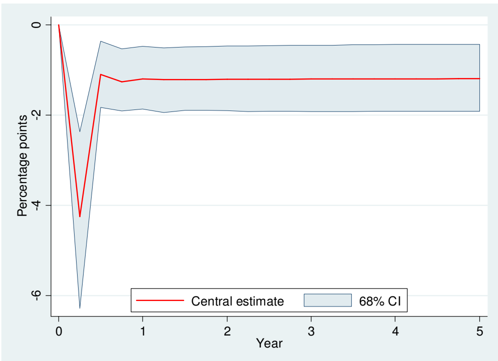


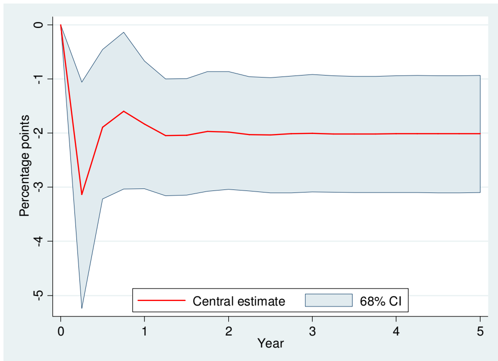
Household unsecured



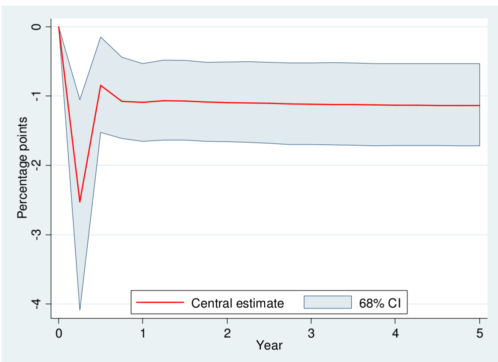


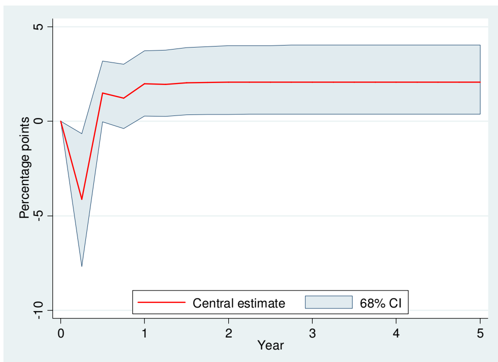
CRE corporates





Non-CRE corporates



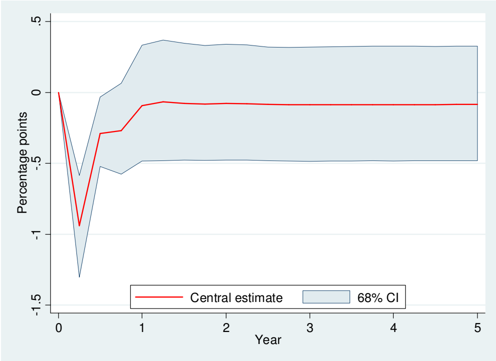


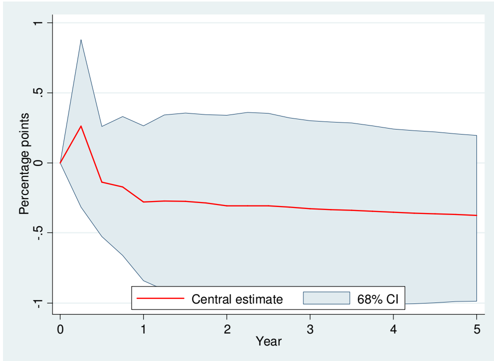
Loan growth impulse responses following a permanent one percentage point increase in the capital requirement at time 0.

Chart A3: Loan growth impulse responses for increases and decreases in capital requirements

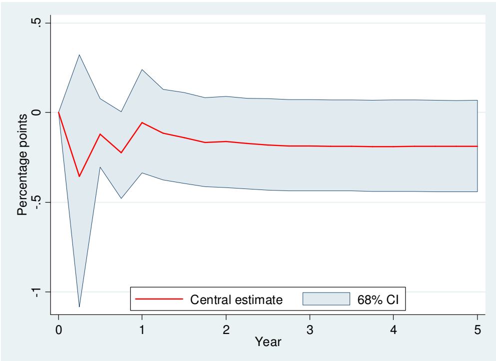
1pp increase in capital requirement	1pp decrease in capital requirement

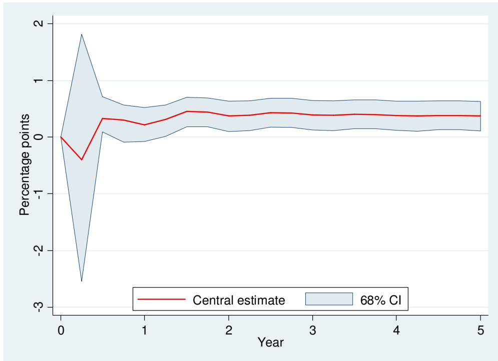
Household secured



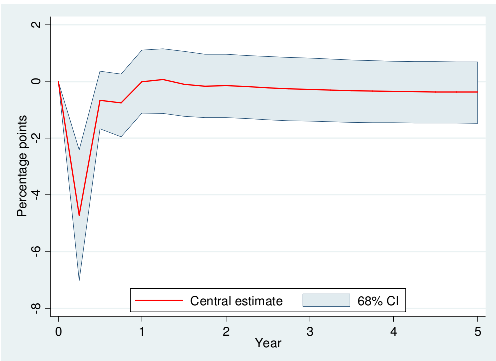


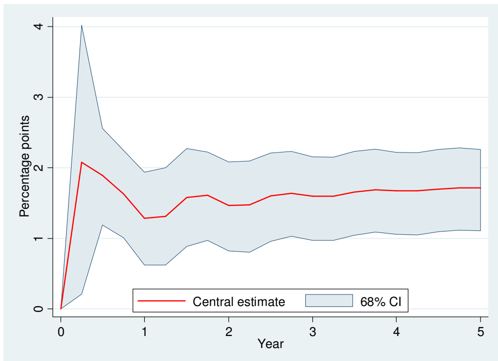
Household unsecured



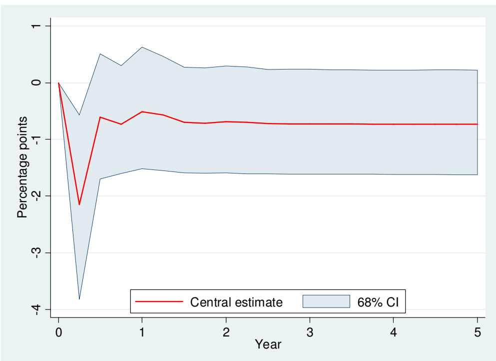


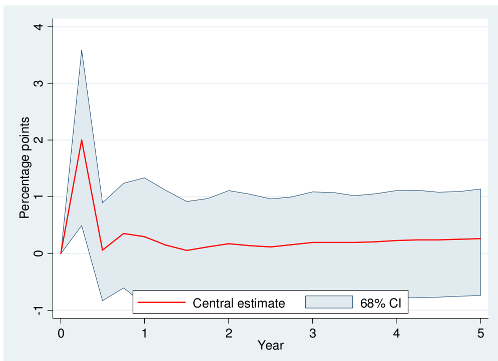
CRE corporates





Non-CRE corporates





The first (second) column shows loan growth impulse responses following a permanent one percentage point increase (decrease) in capital requirements, estimated on banks that experienced an increase (decrease) or no change in their capital requirement over the previous four quarters.

d) Business cycle variation in banks' responses

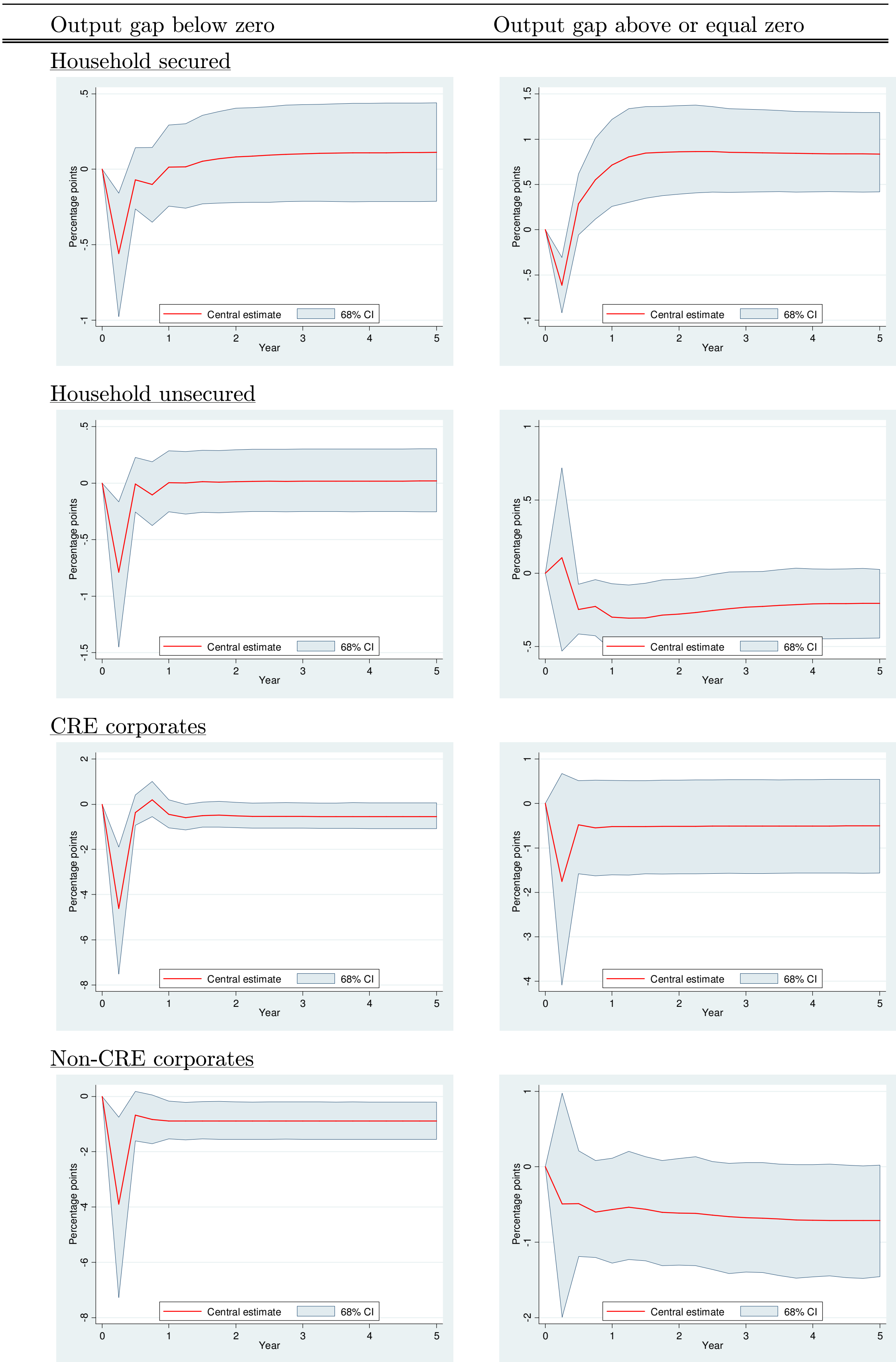
We examine variation over the business cycle by estimating responses when the output gap is positive and when it is negative. The specification is similar to that in equations (A1) and (A2), but with the lagged size dummy replaced by a lagged output gap dummy.[25] We use output gap figures from the Office for Budget Responsibility (see Pybus (2011) and OBR (2013)). The results are presented in Chart A4.

e) Heterogeneity by size of capital buffer

Finally, we look at the extent to which banks with large capital buffers tend to respond differently to a change in capital requirements than those with small buffers. We do so using a specification similar to that in equations (A1) and (A2), but with the lagged size dummy based on whether the bank's lagged capital buffer is above or below a threshold. The choice of threshold reflects a trade-off between having sufficient observations in both groups for estimation and being close enough to zero that one would expect banks in the low capital buffer group to be particularly affected by a change in capital requirements. The results presented in Chart A5 are based on a threshold of 1.5 per cent.

[25] Contrary to the lagged size dummy, the lagged output gap dummy is not included on its own because it does not vary across firms within quarters.

Chart A4: Loan growth impulse responses by output gap

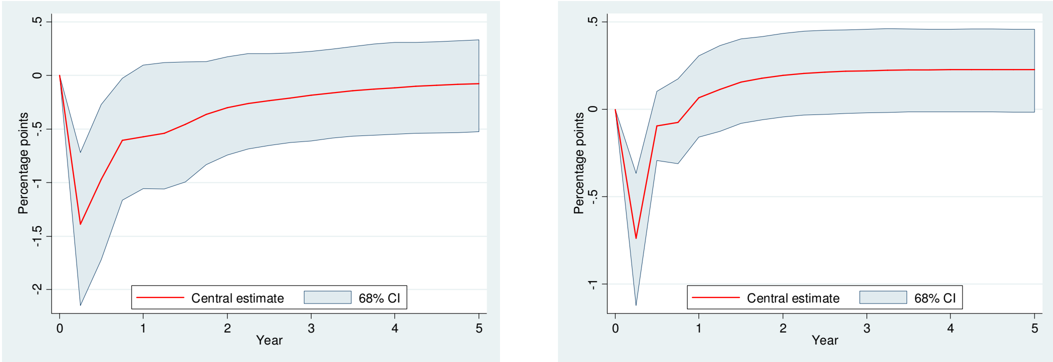


Loan growth impulse responses following a permanent one percentage point increase in the capital requirement at time 0. Output gap figures used to split the sample are from the Office for Budget Responsibility (see Pybus (2011) and OBR (2013)).

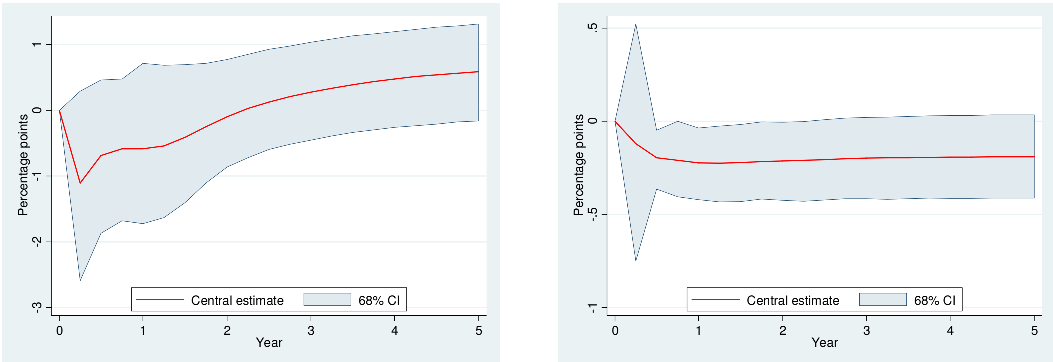
Chart A5: Loan growth impulse responses by capital buffer size

Capital buffer below 1.5	Capital buffer above or equal to 1.5

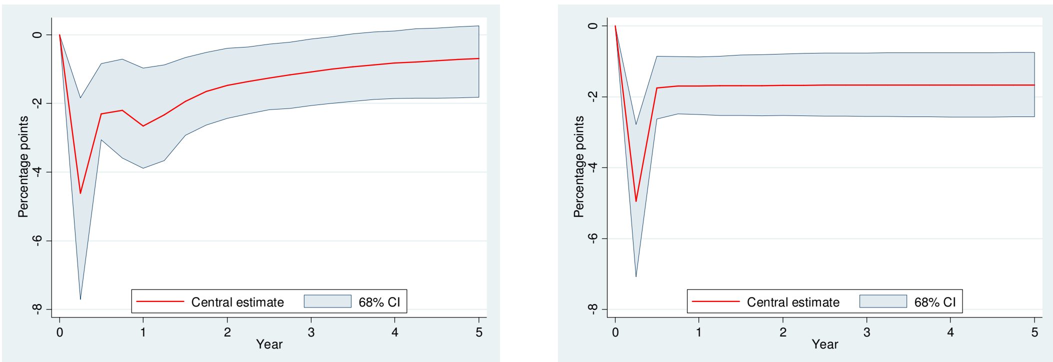
Household secured



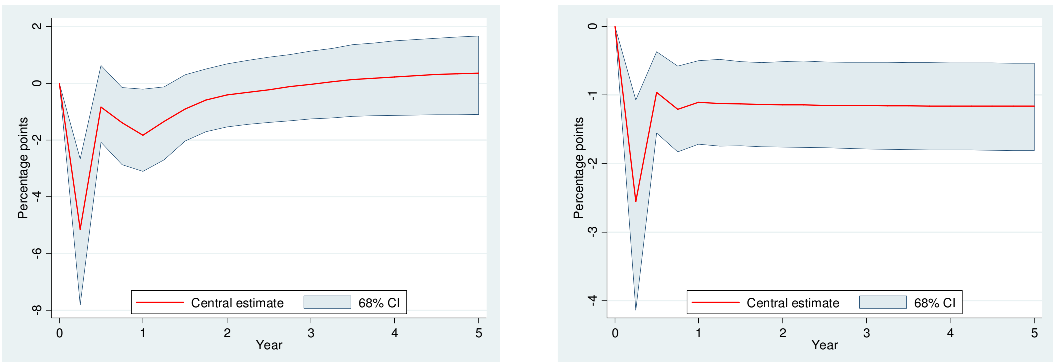
Household unsecured



CRE corporates



Non-CRE corporates



Loan growth impulse responses following a permanent one percentage point increase in the capital requirement at time 0.

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