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Jonathan Bridges,[1] David Gregory,[2] Mette Nielsen,[3] Silvia Pezzini,[4] Amar Radia[5] and Marco Spaltro[6]

Abstract

We estimate the effect of changes in microprudential regulatory capital requirements on bank capital ratios and bank lending. We do so by running panel regressions using a rich new data set, exploiting variation in individual bank capital requirements in the United Kingdom from 1990–2011. There are two key results. 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 over 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, on average, cut (in descending order based on point estimates) loan growth for commercial real estate, other corporates and household secured lending. The response of unsecured household lending is smaller and insignificant over the first year as a whole. Loan growth mostly recovers within three years. While estimated over a different policy regime and at the individual bank level, these results may contain some insights into how changing capital requirements might affect lending in a macroprudential regime. However, during the transition to higher global regulatory standards, the effects of changes in capital requirements may be different. For example, increasing capital requirements might augment rather than reduce lending for initially undercapitalised banks.

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

JEL classification: G21, G28.

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Contents

Summary

This paper investigates the effect of changes in regulatory capital requirements on bank capital and lending to UK households and firms. It is an empirical study drawing on a new bank-by-bank data set, exploiting variation in individual bank capital requirements in the United Kingdom between 1990 and 2011. There are two key results. First, regulatory requirements impact bank capital ratios; banks typically rebuild the "buffer" in their capital ratios above the regulatory minimum following an increase in that minimum requirement.[1] Second, changes in regulatory capital requirements affect bank lending. Results vary across sectors, but in response to an increase in capital requirements, loan growth typically falls in the year following the regulatory change and recovers within three years.

Empirical evidence on the link between regulatory capital requirements and bank lending is also of interest to policymakers. The financial crisis has led to support for the use of capital requirements as a tool to mitigate risks in the financial system. In the United Kingdom, the Financial Policy Committee (FPC) is responsible for setting time-varying capital requirements on sectoral lending.

The effect of such capital requirements might differ from the effect of microprudential policy. As a result, the results from our study cannot be directly mapped across to how changing capital requirements are likely to affect bank capital and lending in a macroprudential framework; but they provide a useful guide to how banks have adjusted their capital ratios and lending structure on average in response to past microprudential supervisory actions. For example, banks might take a different approach to restoring capital buffers when other banks are subject to the same policy change and measures are public; expectations of forthcoming policy changes might lead to earlier reactions by banks; and there might be a different degree of 'leakages' where entities not domestically regulated step in with new lending. 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.

This paper uses a rich new data set constructed at the bank group level. It matches high-quality lending data with supervisory data on bank capital and capital requirements. Supervisory data include confidential bank-specific and time-varying capital requirements set by the Bank of England and the Financial Services Authority (FSA) in the United Kingdom between 1990 and 2011, which allow us to estimate directly the relationship between changes in capital requirements and individual bank lending behaviour. Lending data are adjusted to give a unique measure of true lending flows, rather than relying on changes in stock positions as a proxy; and we analyse lending responses at the sectoral level, such that both credit supply and demand conditions are allowed to vary across different sectors of the economy.

[1] A bank's capital ratio is given by total regulatory capital as a proportion of total risk-weighted assets. A bank's capital "buffer" is given by the actual capital ratio minus that bank's minimum required capital ratio, as determined by the regulator.

The bank-by-bank data set is exploited using two sets of panel regressions. First, we regress the actual capital ratio held by each bank on that bank's regulatory minimum capital ratio. That allows an assessment of whether regulatory requirements affect the capital banks hold. Second, the loan growth of each bank to different parts of the economy is regressed on that bank's individual regulatory requirement and on its actual capital ratio. By estimating these two equations, both the direct impact of a change in capital requirements on lending and any indirect impact via the response of bank capital can be taken into account when plotting the response of bank lending over time.

These regressions suggest that changes in regulatory capital requirements did impact bank behaviour over the sample period. First, we find that changes in regulatory requirements typically lead to a change in actual capital ratios – in response to an increase in the minimum ratio, banks tend to gradually rebuild the buffers that they initially held above the regulatory minimum. Second, capital requirements affect lending with different responses in different sectors of the economy – in the year following an increase, banks tend to cut (in descending order) lending to commercial real estate, to other corporates and household secured lending. The response of unsecured household lending is close to zero over the first year as a whole. Loan growth mostly recovers within three years. Finally, preliminary analysis suggests that banks' responses vary depending on bank size, capital buffers held, the business cycle, and the direction of the change in capital requirements.

These findings contribute to the debate on whether the Modigliani-Miller propositions hold (i.e. whether changes in the composition of a bank's liabilities affect the bank's overall cost of funds and credit supply), in which case changing banks' capital requirements would not affect lending. In practice, the empirical literature has identified a range of frictions (with taxation of debt versus equity being frequently mentioned) such that the debt/capital structure of banks may not be neutral for credit supply. Our paper confirms that regulatory requirements tend to affect capital ratios permanently and credit supply temporarily.

1 Introduction

In this paper, we attempt to identify the effect of changing regulatory capital requirements on bank capital and bank lending. 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 trace 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. We also do preliminary analysis 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 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 (as advocated by Den Haan, Sumner and Yamashiro, 2007), 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 (rather than changes in stocks) – a key innovation as demonstrated below.

We find two key results. 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 over 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 commercial real estate (CRE), other corporates and household secured lending. The response of unsecured household lending is shallower and not significantly different from zero over the first year as a whole. We find that 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. Finally, preliminary analysis suggests that banks' responses differ depending on their size, capital buffers held, the business cycle, and the direction of the change in capital requirements.

These findings help shed light on a widely debated theoretical question. The existence of an effect of capital requirements on lending hinges on the failure of the Modigliani-Miller (1958) propositions. In the context of the banking sector, Modigliani-Miller implies that, for a given portfolio of assets, changes in the composition of a bank's liabilities should not affect the overall cost of funds for the bank, and therefore the supply of credit. But a range of possible frictions might mean that capital ratios – and capital requirements, to the extent that they influence capital ratios – are not neutral for credit supply. Frictions that are often cited include the tax deductibility of debt and asymmetric information. But in the short term, there could also be

frictions associated with the raising of equity capital (eg inelastic investor demand). Ultimately, this question can only be settled empirically.

Empirical evidence on the link between capital requirements and bank lending, especially at the sectoral level, is also of great interest to policymakers, given that the financial crisis has led to widespread support for the use of capital requirements as a policy tool (for example Yellen (2010) and Hanson, Kashyap and Stein (2011)). The FPC has Direction powers over sectoral capital requirements and Her Majesty's Government has proposed making the FPC responsible for setting the countercyclical capital buffer.[2] Although our findings are derived from a microprudential supervisory regime, they may contain insights about how changes in capital requirements will affect lending in the forthcoming macroprudential regime.

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

Friedman (1991) noted that: "traditionally, most economists have regarded the fact that banks hold capital as at best a macroeconomic irrelevance and at worst a pedagogical inconvenience." Since then, a large literature has developed seeking to identify the effect of bank balance sheet conditions – including bank capital – on lending and the wider economy. In this section, we review the theoretical and empirical literature on the effects of capital, and capital requirements, on the supply of credit, and place our study in the context of that literature.

The theoretical benchmark for understanding the impact of such a shock 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 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 asymmetric information – Myers and Majluf (1984) – and debt overhang – Myers (1977). 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 (eg 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] Bank of England (2014) provides additional information on these tools.

The growing number of studies on the relationship between bank capital and lending behaviour can be divided into two broad buckets: those investigating the impact of shocks to capital *resources* on bank lending – that is shocks to observed bank capital levels or ratios; and those investigating the impact of shocks to regulatory capital *requirements* on bank lending. Given the poverty of data on actual capital *requirements*, shocks to capital *resources* are often used as a proxy for capital requirements by making an assumption about how banks alter capital ratios in response to a regulatory change. Alfon, Argimón and Bascuñana-Ambrós (2005) provide evidence for that assumption; they find that UK banks pass through around 50% of an increase in capital requirements to their capital ratios, though the rate of pass-through is only 20% for reductions in capital requirements.

2.1 Impact of changes in capital resources 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 – limited banks' ability to make loans, although the authors are sceptical that the credit crunch played a major role in worsening the recession.[3] Furfine (2000), in a theoretical model calibrated to the US data, does find a role for capital regulation in explaining the decline in loan growth and rise in bank capital. But Sharpe (1995) argues that the evidence in favour of a capital crunch is not particularly conclusive.

Peek and Rosengren (1997) use a natural experiment to overcome difficulties in identifying whether changes to bank lending reflect shocks to credit supply or credit demand. They analyse the effects of capital shocks on the lending of the branches and subsidiaries of Japanese banks located in the United States. The parent Japanese banks, which were allowed to treat unrealised gains on equity investments as capital, suffered a large capital shock after the collapse of equity prices in the late 1980s. By focusing on the US lending operations of these banks, the authors were able to isolate the credit supply effects of a fall in bank capital. They find that for Japanese banks' US branches, 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, roughly translating into a 6 percentage point fall in the stock of lending.

In the absence of natural experiments, an alternative identification strategy exploits individual loan-level data (where availability allows), including matched bank and borrower information. Jimenez *et al* (2010) exploit a matched panel for Spain and find that lending varies with the capital and liquidity positions of both banks and borrowers as well as with macroeconomic conditions. Albertazzi and Marchetti (2010) find similar results when using loan-level data on Italian banks for the period following the collapse of Lehman Brothers.

Heid, Porath and Stolz (2004), using dynamic panel data techniques on data from German savings banks over the period 1993-2000, find evidence that capital buffers influence decisions over both capital and risk-weighted assets. They find that banks with lower buffers attempt to

[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 decline in lending.

rebuild them by simultaneously raising capital and lowering risk-weighted assets and that banks with larger buffers maintain them by increasing risk-weighted assets when capital increases. Stolz and Wedow (2005), however, using data for German cooperative banks as well as 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.

In a more top-down approach, Noss and Toffano (2014) study the dynamics of capital and lending at the aggregate level in the United Kingdom, using sign restrictions to identify shocks that fit an assumed pattern of responses for macro-financial variables and assuming that capital and capital requirements move in lockstep. 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 92 countries, Fonseca, Gonzalez and Pereira da Silva (2010) find that banks with larger capital buffers charge lower interest rates on their lending and pay lower interest rates on their borrowing. They find that this effect is larger in developing countries and during downturns.

2.2 Impact of changes in capital requirements on lending

Our approach falls into the second branch of literature, which makes the direct connection between changes in capital requirements and bank lending behaviour. Recent micro-econometric studies tend to focus on the UK because of the relatively unique nature of the regulatory capital regime, where capital requirements have been set differently across firms for the past two decades.

Ediz, Michael and Perraudin (1998), in a study using confidential supervisory data for UK banks over the period 1989-95, find that capital requirements significantly affect bank's capital ratios, but that firms appear to adjust by directly boosting their level of capital rather than reducing lending.

One 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 of 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), which was 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 arrive at a series of estimates across different jurisdictions for the impact of a one percentage point increase in the target capital on lending volumes. 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.

The paper most closely related to ours is Aiyar, Calomiris and Wieladek (2014). Their focus is on the question of whether increases in capital requirements 'leak' in the sense that foreign branches can offset reductions in lending by regulated banks. As part of their study, they also make use of UK data on individual capital requirements, but use a simpler panel data fixed effects framework, regressing loan growth directly on changes in capital requirements and considering only lending to PNFCs (which comprises about a quarter of the stock of loans to the UK real economy; Table A). They find that the average effect of a 1pp increase in capital requirements is a cumulative reduction in PNFC loan growth of 5.7-8.0 percentage points.

There are significant differences between our approach and Aiyar, Calomiris and Wieladek (2014) in terms of model specification and data. Our model takes account of the effect of capital requirements on capital resources, and in turn on lending; and does not restrict the effect on loan growth to be zero in the long run. We consider a longer sample period – 1990-2011 rather than 1998-2007; use consolidated rather than unconsolidated data; and establish a new banking unit after mergers rather than synthetically consolidating pre-merger entities. We also offer – to our knowledge – a novel extension by estimating panel data lending models at the sectoral rather than aggregate level. This allows us to test whether banks' behavioural response to a change in capital requirements is uniform across household secured, household unsecured, CRE and other corporate lending. By estimating regressions for loan growth to each sector separately, we are also better able to control for sectoral variations in credit demand, allowing us to more accurately identify the response of lending supply to changes in regulatory capital requirements. Finally we use data on 'true' lending flows, an important innovation as demonstrated by Chart 1 below. These data have not been used in any previous UK studies on this topic. A fuller discussion of each of these aspects of the data can be found in the next section.

3 Data

3.1 Data set construction

A strength of our study is the rich panel data set of UK-supervised banks that we have constructed. This data set marries high-quality sectoral lending data with unique supervisory data on capital and capital requirements, and possesses several valuable features. First, it contains data on bank-specific, time-varying, capital requirements. Second, the lending flows in our data reflect 'true' bank lending behaviour, a novel improvement in the empirical panel literature on bank lending. Third, we construct those true lending flows at the sectoral level. Fourth, the data are constructed at the bank group level. And, fifth, it covers a longer time period (1990-2011) than previously used data sets. In this section we describe the data set, highlight its strengths and present descriptive statistics.

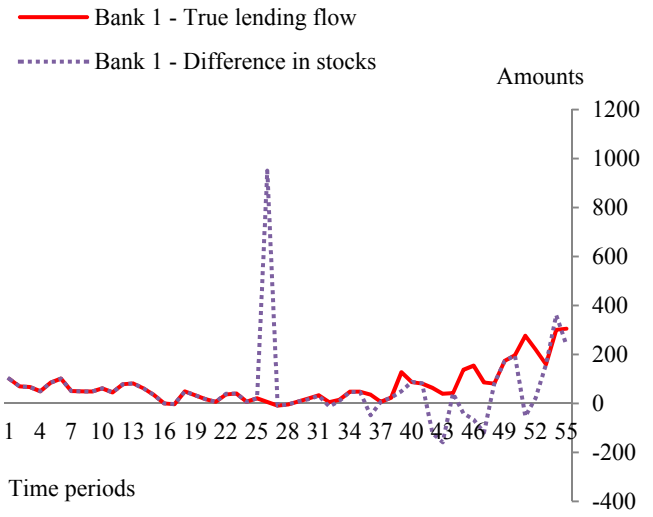
An important contribution is that our paper makes use of novel data on 'true lending flows' as opposed to 'changes in loan stocks', a distinction that is far from trivial as we explain below. We retrieve true lending flows such that they reflect only 'transactions', as defined by international standards 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, exchange rate effects, reporting changes, changes to group structures, reclassifications and changes in the values of securities and repos (Equation (1)). The 'true flows' used in this paper correct for those effects at the bank level by using additional information from individual banks' monetary returns collected by the Bank of England.

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

Comparing the true flows to differences in stocks reveals substantial differences, as shown in Chart 1 for a representative bank (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. This contamination is potentially especially severe when examining the role of bank capital. For example, a write-off would lead to a contemporaneous fall in both capital and the loan stock, thereby generating a spurious correlation between the two.

Chart 1: Data quality of true lending flows



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

Throughout this paper, we use the 'true' lending flows described above calculated at the (National Accounts) sectoral level. Neither of these elements has been used in previous UK studies into the effects of capital requirements on bank behaviour.[4] As argued by Den Haan, Sumner and Yamashiro (2007), 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

[4] To our knowledge, existing literature which exploits non-UK data does not use 'true' lending flows either. Though it would be possible to construct a true flows series from loan-level credit register data used in some of the literature – eg Jimenez et al (2010).

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.

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 A 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 A: Size and regulatory risk weights of each lending sector

	Share of outstanding stock of loans	Basel I risk weights	Basel II (standardised) risk weights[6]
Secured lending to households	65%	50%	35% for LTV≤ 80% Up to 45% for LTVs in excess of 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

Source: Bank of England

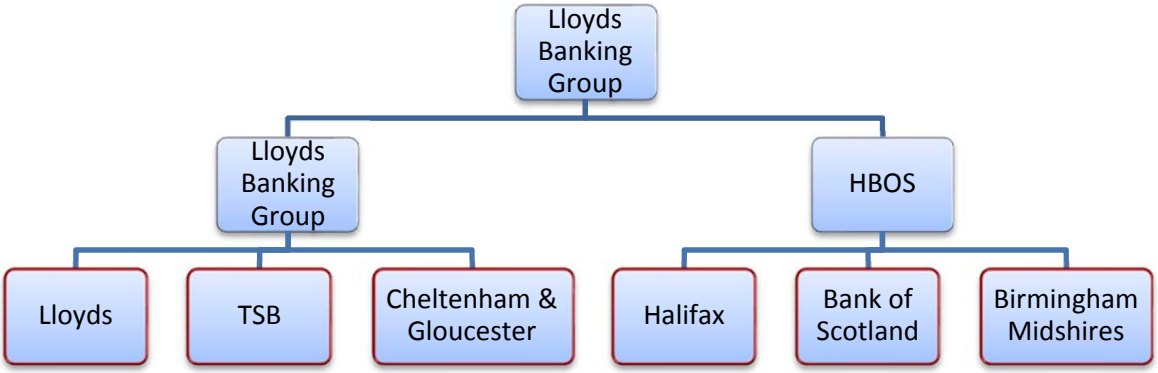
Another key feature of our data set is that it is constructed at the banking group level, on what is termed a 'consolidated' basis, as opposed to an unconsolidated (individual entity) basis. The reason is that both lending and capital decisions are, in our view, likely to be determined at the group level. Banking groups typically report their lending strategy and results at the group level. And the capital resources and constraints of a subsidiary should influence decisions at a group level because shocks to these resources and constraints permeate through the whole group. This importance of group cash flow and capital resources is highlighted in Houston, James and Marcus (1997). And 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 'quasi-consolidated' the monetary returns data (which are submitted only on an unconsolidated basis to reflect the UK operations of an individual entity) by summing across constituent parts of a banking group.[7] As an example, Figure 1 shows a simplified version of

[5] 'Real economy' lending is defined as the stock of loans to households and PNFCs.
[6] Note, however, that larger UK banks implemented the Internal Ratings Based (IRB) approach rather than Standardised approach under Basel II.
[7] 'Quasi-consolidated' data do not strip out intra-group activity that is not included in truly consolidated data.

Lloyds Banking Group. Our consolidated data reflect lending and capital for the group as a whole, whereas an unconsolidated data set would contain each of the six sub-entities (Lloyds, TSB, Cheltenham & Gloucester, Halifax, Bank of Scotland, Birmingham Midshires) separately.

Figure 1: Example group structure for Lloyds Banking Group



The data on bank capital resources and capital requirements, which come from the regulatory returns collected initially by the Bank of England and later by the FSA, are available on both a consolidated and unconsolidated basis. We use the former, which reflects the global balance sheets of banking groups regulated by the FSA, and previously, the Bank of England.[8] The regulatory returns contain detailed information on capital adequacy, such as the total amount of risk-weighted assets and the bank-specific capital requirement (sometimes called the 'trigger' capital requirement – see Box 1).

Our data set is adjusted to account for the considerable number of mergers and acquisitions that occurred in our sample period. We split the series at the time of any M&A activity and excluded at least a quarter of data as balance sheets can demonstrate peculiar behaviour around the time of mergers and acquisitions.[9] This treatment makes our sample less balanced. But we see this cost as preferable to backwards engineering a synthetic aggregate of merged banks, as done elsewhere in the literature. We are not convinced that separate competitor banks, with different business models and balance sheets, can be treated as if they were one unit before the merger. In addition, several other manipulations have been made in order to clean the data, as detailed in Appendix 1.

Box 1: The UK prudential regime

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%, the UK regulators set bank-specific minimum capital requirements.

[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.

[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.

Before the establishment of the FSA, the Bank of England set bank-specific minimum total capital requirements (known as 'trigger ratios') as well as target ratios, typically set 50-100bps above the trigger to avoid an accidental breach.[10] After this power was handed over to the FSA in 2001, trigger ratios were renamed Individual Capital Guidance (ICG) and subsequently became set as part of the Pillar 2 process under Basel II.

Trigger ratios are set to compensate for the uniformity of other aspects of the capital adequacy framework (e.g. risk weights). A bank's trigger ratio is based on bank-specific factors such as the quality of risk management, the quality of internal control and accounting systems, plans for future developments of the business, its size and position in chosen markets, and the future outlook in those markets.

3.2 Descriptive statistics

Our panel data set includes data from 1990 Q1 until 2011 Q3 and thus captures a full business cycle. We have included all banks, both active and inactive, who have reported total UK assets greater than £5 billion at any time since 1990 Q1. As a result, our panel contains 53 banking groups, each with an average of 30 quarters of data.

Table B presents the summary statistics of the most important capital adequacy and lending variables: 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 PNFCs.[11]

Table B: Summary statistics[12]

	# 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 PNFC 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

Sources: Bank of England and FSA.

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

[10] The Bank of England policy of setting trigger and target ratios dates back to before the implementation of Basel I.

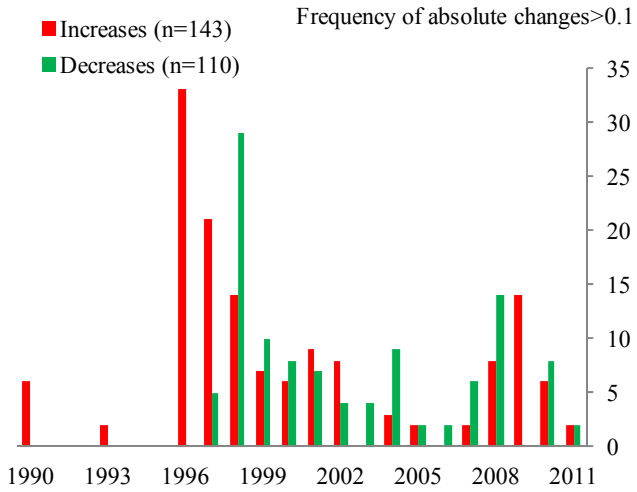
[11] Throughout this paper, minimum capital requirements and actual capital ratios are defined in 'total capital' terms. In other words, the numerator of these ratios includes all types of regulatory capital.

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

sample, with a slight prevalence of increases (143 occurrences) over decreases (110 occurrences). Chart 3 shows that the bulk of changes in minimum capital requirements over the sample period were between 0 and 1 in absolute value.

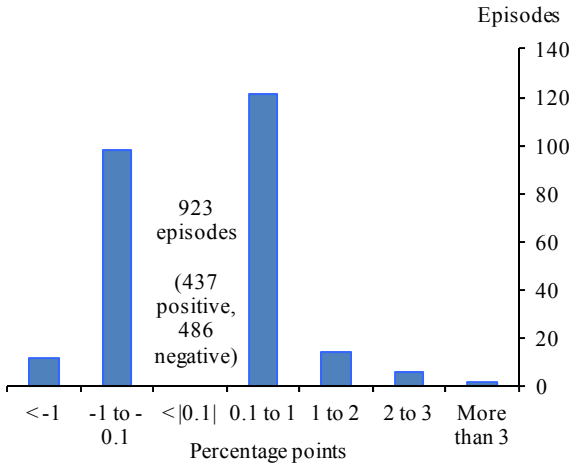
Chart 4 illustrates how capital buffers (i.e. the difference between the overall capital ratio and the minimum requirement) broadly fell across banks in the decade leading up to the crisis, before being rebuilt in the last two years of the sample.

Chart 2: Variation in minimum capital requirements



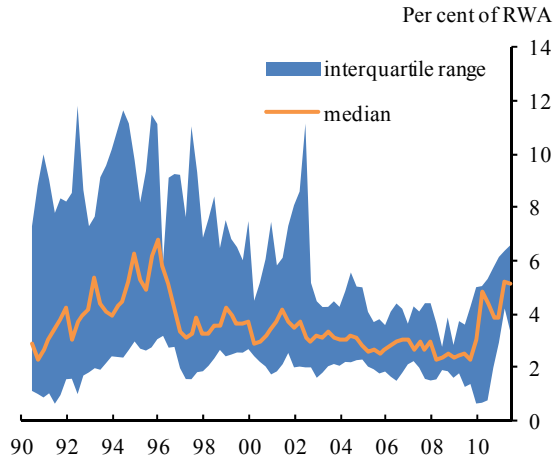
Sources: Bank of England and FSA

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|

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:

$$cap_{it} = \alpha_1 + \sum_{k=1}^{4} \gamma_{1k} cap_{i,t-k} + \sum_{k=1}^{4} \delta_{1k} trig_{i,t-k} + \theta_{11i} + \theta_{12t} + \epsilon_{it} \quad (2)$$

$$\dot{loan}_{it} = \alpha_2 + \sum_{k=1}^{2} \beta_{2k} \dot{loan}_{i,t-k} + \sum_{k=1}^{2} \gamma_{2k} cap_{i,t-k} + \sum_{k=1}^{2} \delta_{2k} trig_{i,t-k} + \varphi_2 M_{it-1} + \theta_{21i} + \theta_{22t} + \varepsilon_{it} \quad (3)$$

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*. θs denote bank and time fixed effects, 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 only once, restricting the sample to those observations where both secured and PNFC loan growth was non-missing while equation (3) is estimated for each different type of lending (secured, unsecured, CRE, and PNFC non-CRE). 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 and 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. 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 same time as demand fell in that particular area.[13] The results are broadly robust to explicitly including macro controls (GDP and inflation) instead of time fixed effects, but the

[13] 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 too large as it would capture the bank's 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 cite Francis and Osborne (2009) noting 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' and then continue to find that changes in write-offs (lagged, present and future) cannot predict changes in capital requirements.

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 number of banks, 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 (T=30). 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 in Section 6 by investigating 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 interval are given by the 16^{th} and 84^{th} percentiles, as is typical in the macro literature following Sims (1999).

5 Results

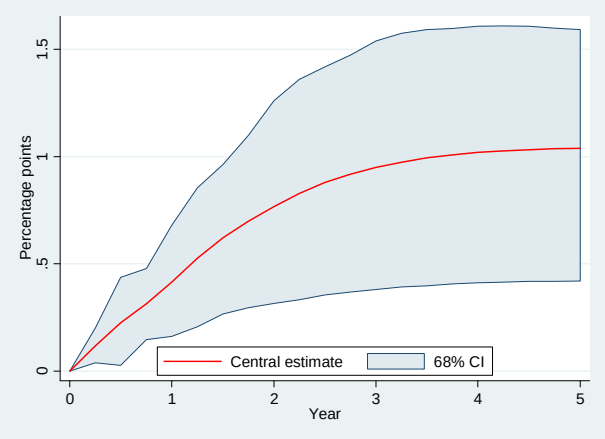
This section presents the main results on how banks adjust their capital and lending following a change in capital requirements, based on the estimates from the two dynamic panel equations (2) and (3). Tables C and D present the capital ratio and sectoral lending responses to a one percentage point permanent 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. Changes in capital requirements are found to significantly affect the observed capital ratio – in other words, regulatory change significantly impacts bank behaviour, rather than being passively absorbed in an equal and offsetting change in the capital buffer held above the regulatory minimum. This result is in line with other studies that use UK data, such as Alfon, Argimón and Bascuñana-Ambrós (2005) and Francis and Osborne (2009).

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 C); 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.

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 C: 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.

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.

a) Household secured lending

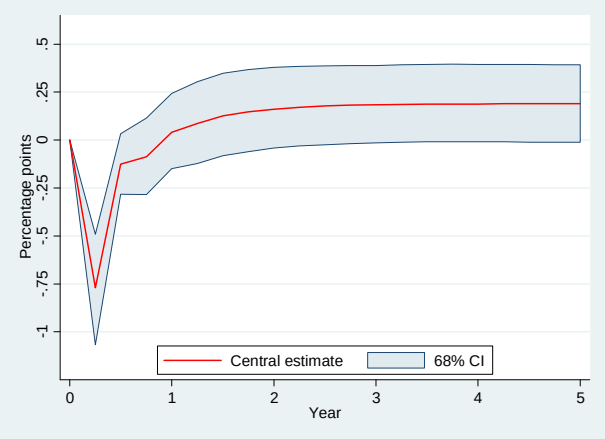
An increase in capital requirements is associated with a temporary reduction in secured loan growth, which on our central estimate lasts less than a year (Chart 6). In the first quarter following the regulatory change, household secured loan growth falls sharply, with a peak impact of reducing the quarterly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

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

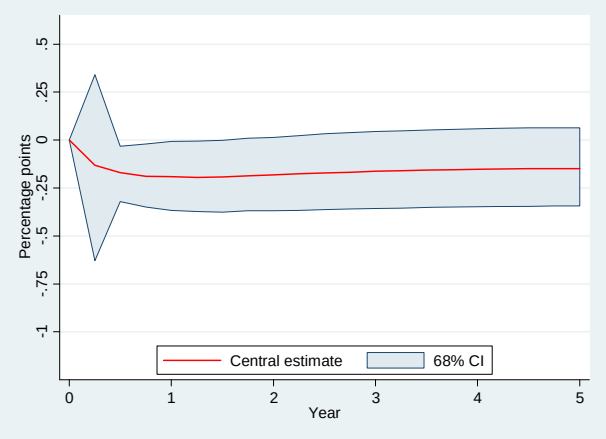
0.2pp after five quarters and a reduction in the loan growth rate of 0.7pp cumulatively after a year and 0.2pp in the long run. Of these effects, only the trough fall in the 5th quarter is significantly below zero.

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



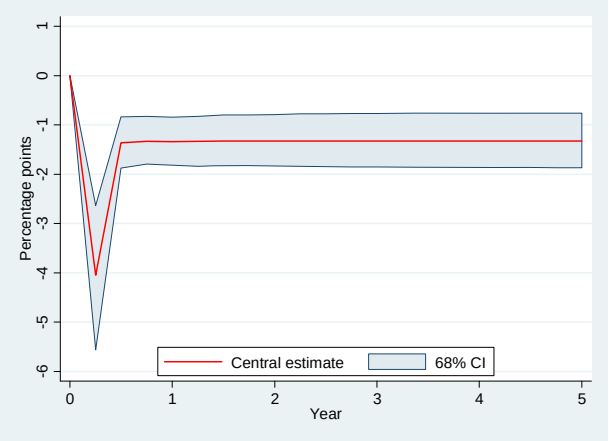
Note: Unsecured loan growth impulse response following a permanent one percentage point increase in the capital requirement at time 0.

c) CRE lending

Turning to corporate lending, we analyse lending to CRE and other industries separately.[14] 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.

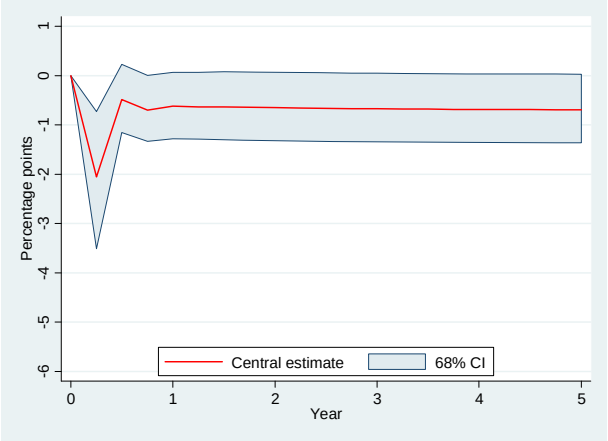
[14] We have also estimated the model for lending to all PNFCs over the longer time series, but there appears to be little effect from changes in capital requirements to lending. This may not be surprising as the equations for all PNFCs rely on lending data from a range of diverse industries with potentially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



Note: Non-CRE PNFC 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 PNFCs in other industries[15] 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.

Table D: 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 PNFC 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.

[15] PNFC non real estate lending is calculated as PNFC 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.

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.[16]

These results are not directly comparable to those of other studies. But a very rough comparison to Macroeconomic Assessment Group (2010), Aiyar, Calomiris and Wieladek (2014) and Noss and Toffano (2014) can be made by calculating the cumulative effect over three years[17] 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, Calomiris and Wieladek (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, Calomiris and Wieladek (2014) – who look at PNFC 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

[16] 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.

[17] 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.

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 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, Pezzini and Rossiter (2010) show that the cost of capital is only a very small fraction of the overall price of an unsecured loan.[18] 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

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

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 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 PNFCs. 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, Feldberg and Lehnert (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 the CRE sector appears to be driven by *reductions* in banks' capital requirements. The effects for the non-CRE PNFC 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).[19]

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 PNFC lending by 3.9pp in that case. In contrast, CRE lending is reduced by only 1.8pp and non-CRE PNFC 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

[19] 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.

secured lending, but the response for times when the output gap is positive exhibits a somewhat puzzling positive response in the long run.

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 PNFC 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.[20] But – for obvious reasons – we lack empirical evidence on as yet untried macroprudential capital requirements. And to the extent that there will be similarities in the way in which banks respond to changes in capital requirements across regimes, our results will contain some quantitative insights into how changing capital requirements in a macroprudential regime might affect lending.

[20] 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 variables

Table A1: Key variables

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 PNFC 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.

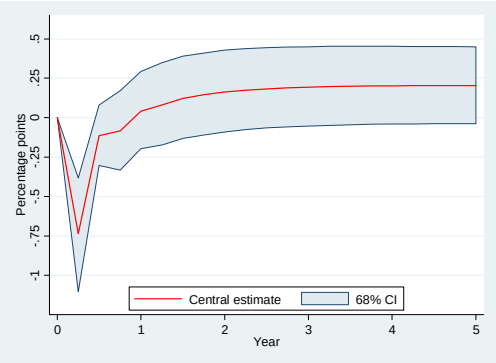
Appendix 4 – Extensions and robustness checks

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



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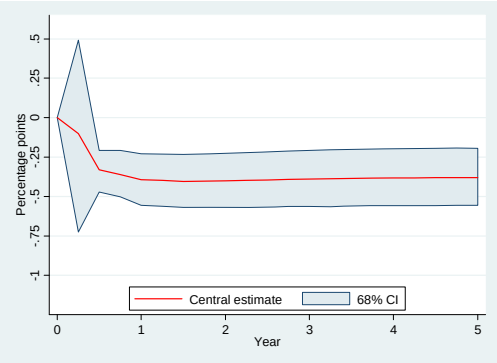

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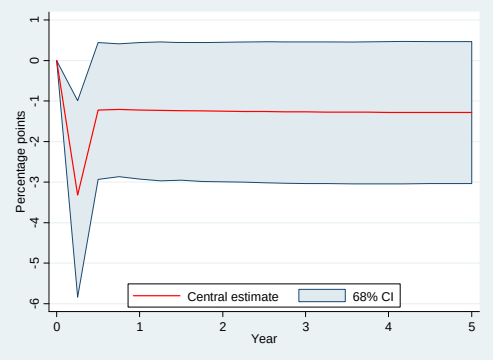
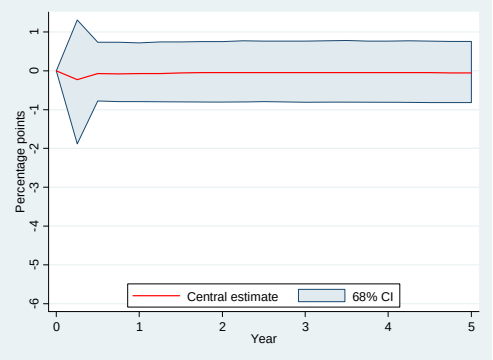


PNFC non-CRE



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.

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
PNFC non-CRE lending	1.20	0.3236	No

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

Our tests suggest that the null hypothesis is not rejected for secured and non-CRE PNFC 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.

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 PNFCs) 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'.

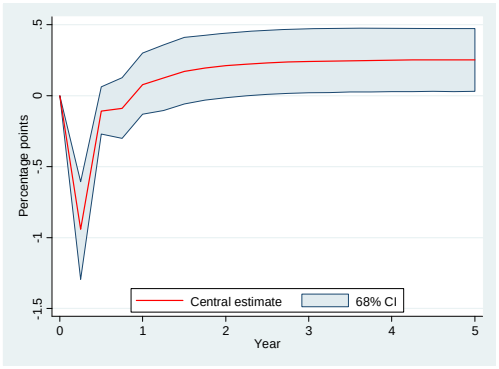
c) Asymmetry between increases and decreases in capital requirements

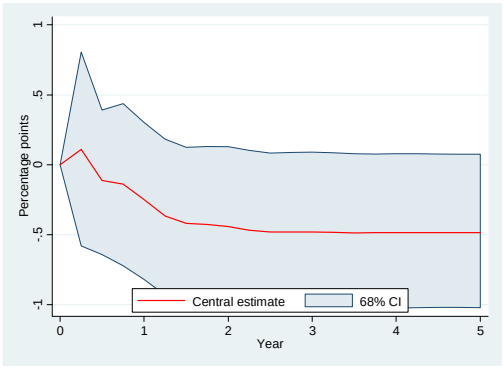
As a preliminary attempt to see whether banks respond symmetrically to increases and decreases in capital requirements, we estimate equations (2) and (3) for subsamples containing episodes of increases and decreases in capital requirements separately. We define an increase in capital requirements episode 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

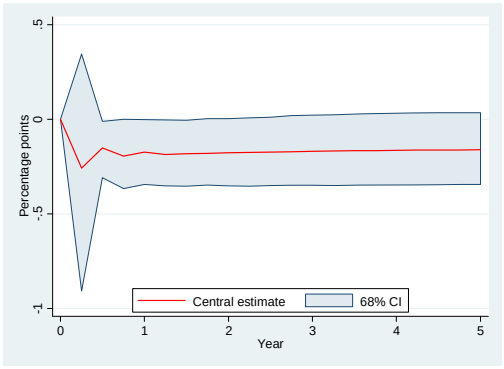
Small banks | Large banks

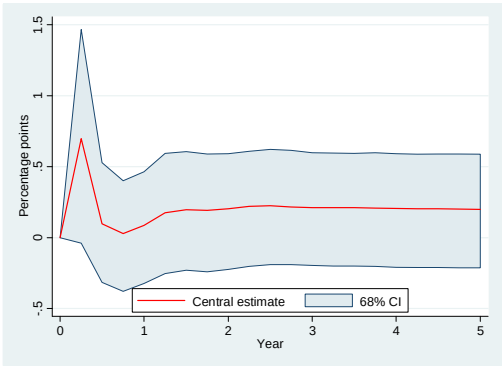
Secured



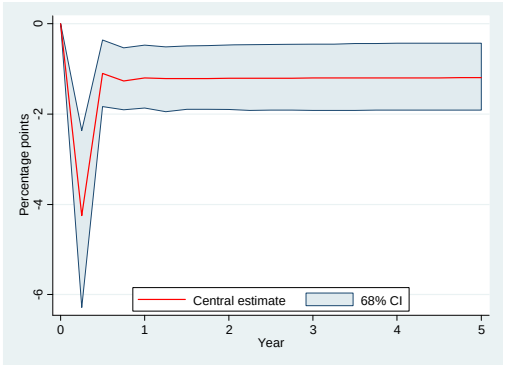


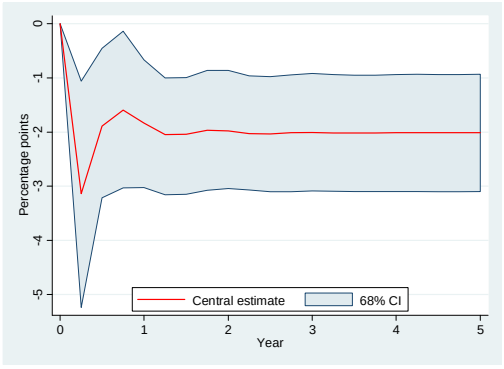
Unsecured



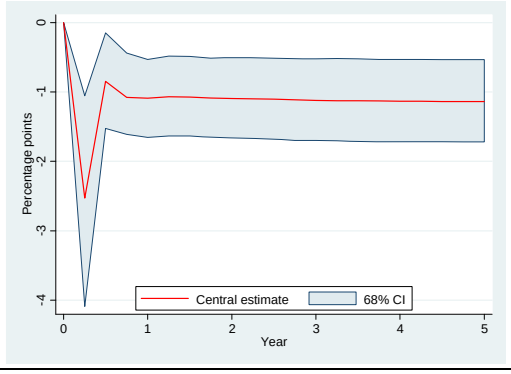


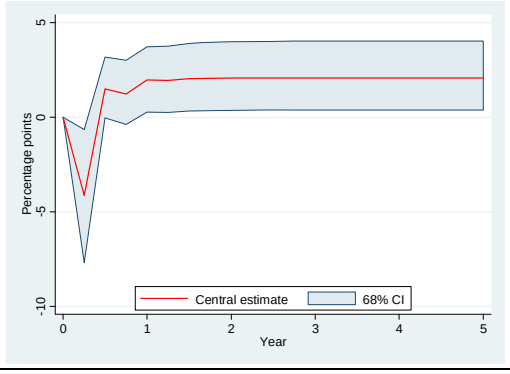
CRE





PNFC non-CRE



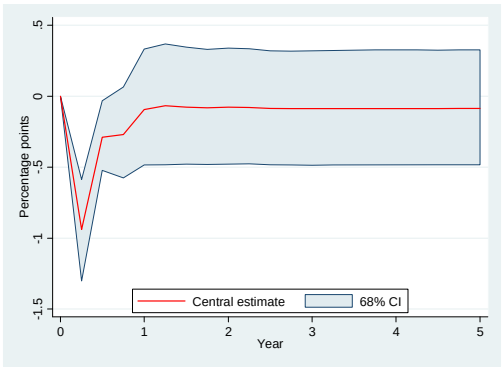


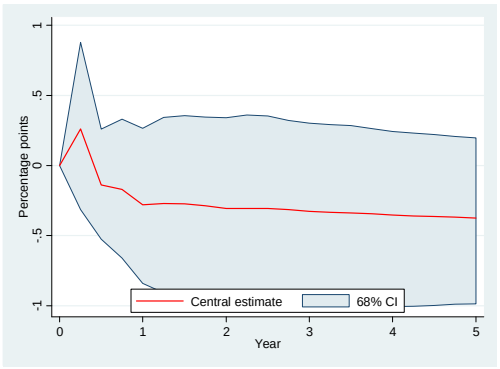
Loan growth impulse responses following a permanent one percentage point increase in the capital requirement at time 0.

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

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

Secured





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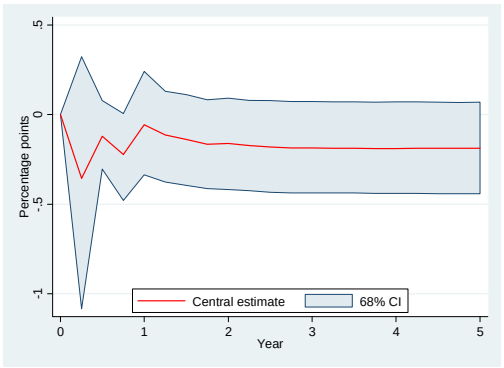
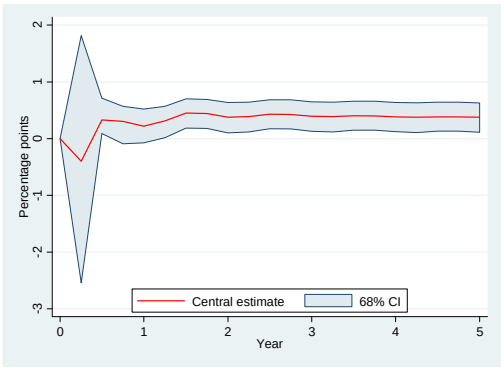
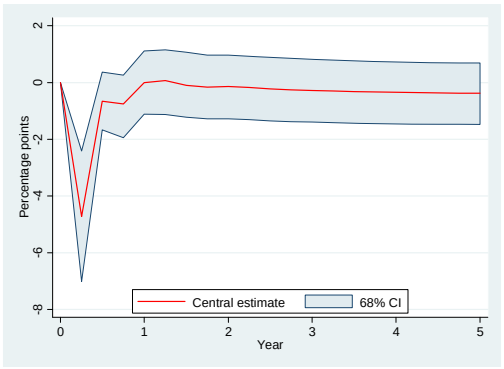
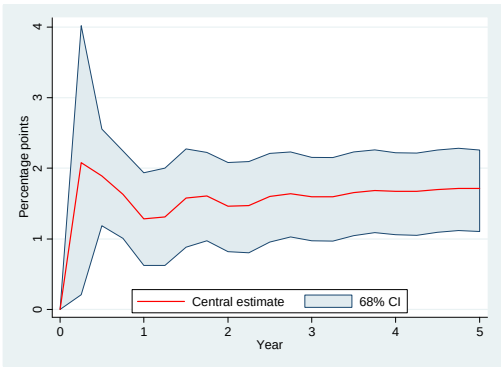


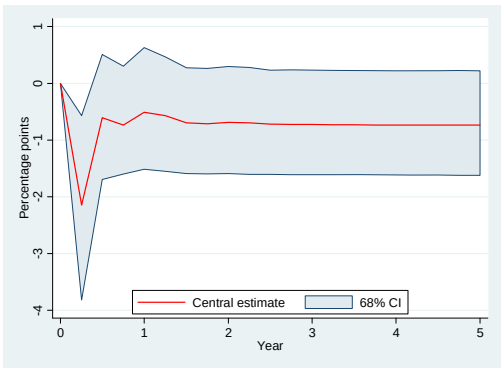


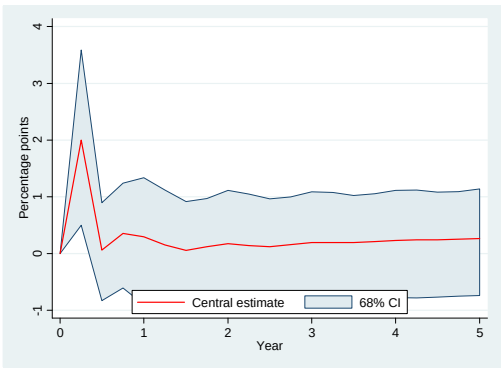
CRE





PNFC non-CRE





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.[21] 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.

[21] 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

Output gap below zero | Output gap above or equal zero

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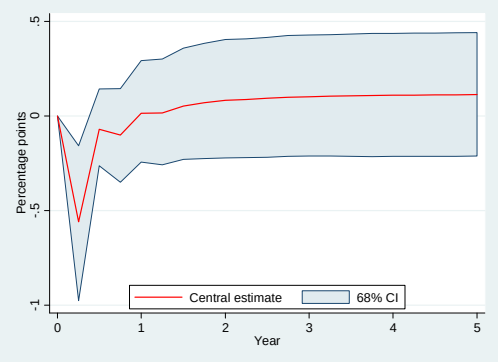

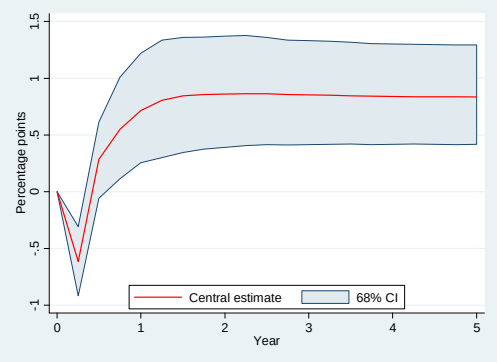

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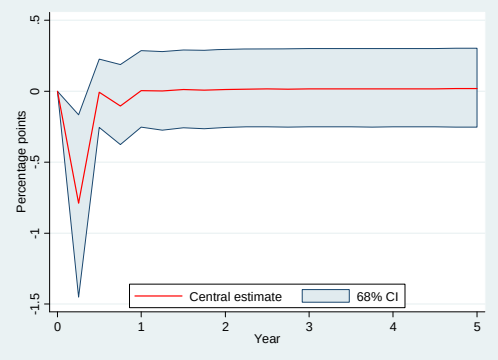

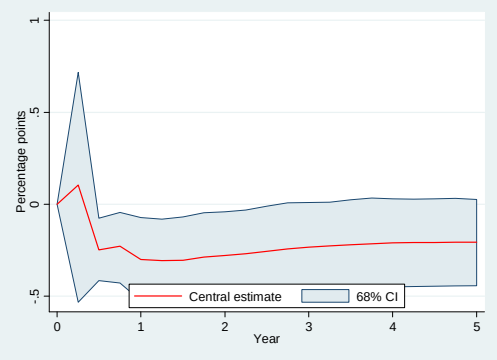

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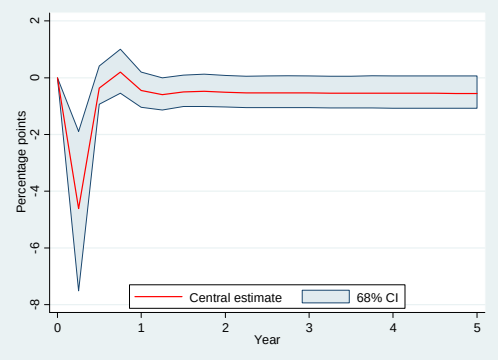
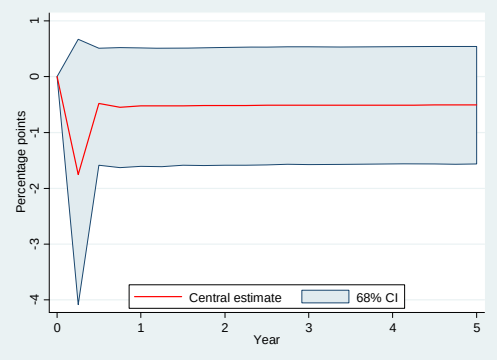
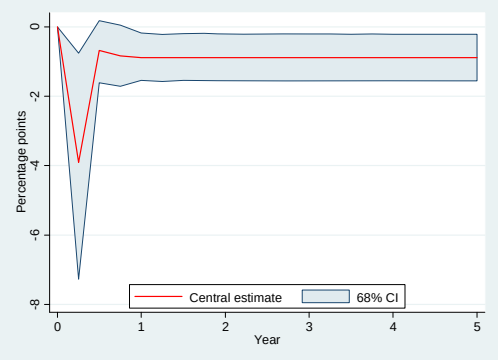
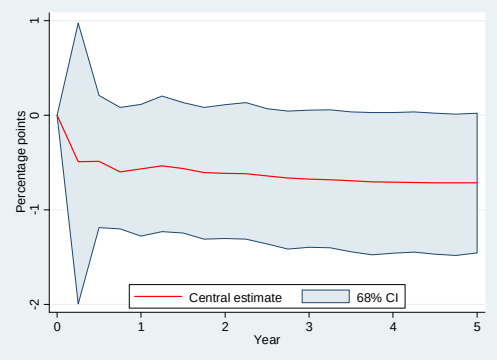




PNFC non-CRE





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

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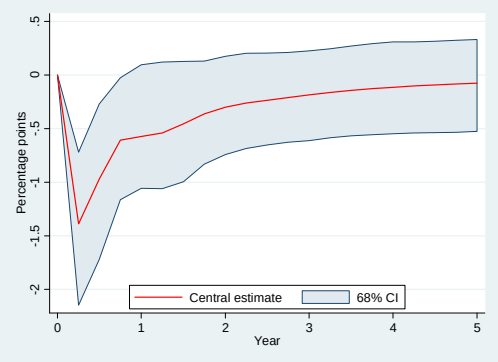

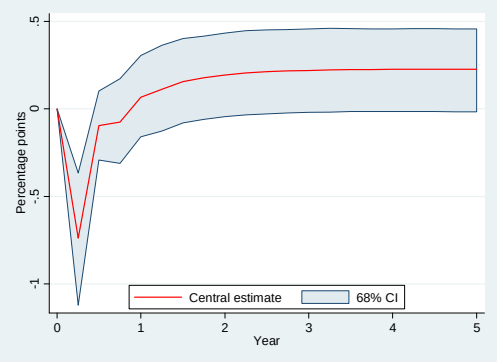

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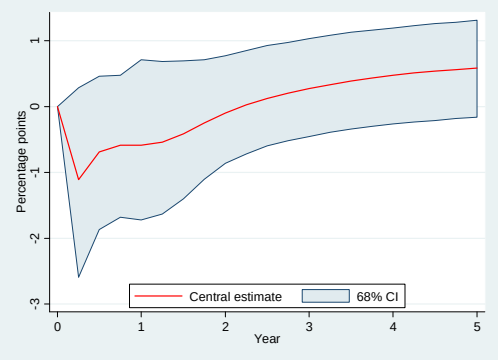

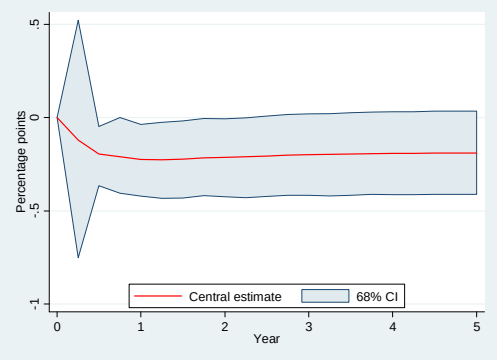

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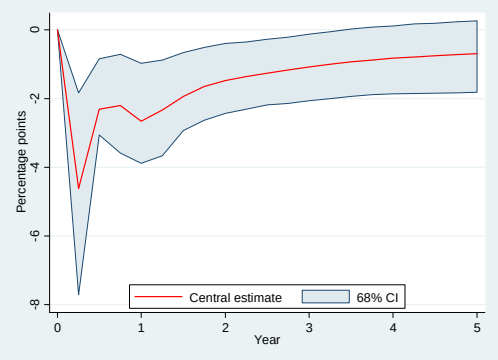
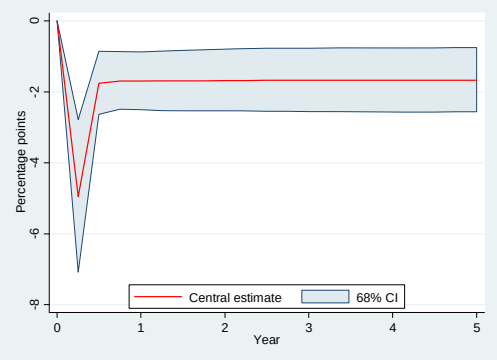
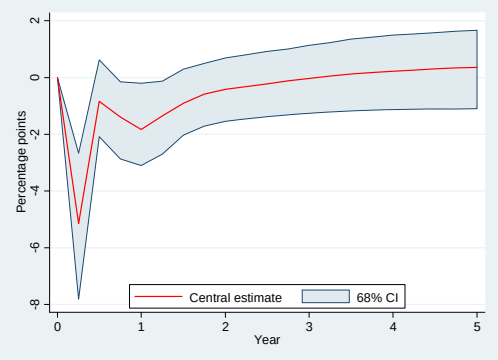
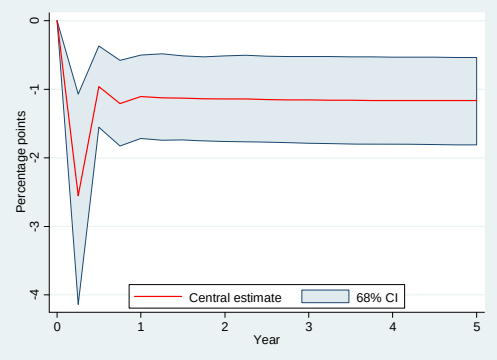




PNFC non-CRE





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

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