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Abstract

We use a proprietary database of individual UK capital requirements spanning 1989 to 2013 and panel regression techniques to evaluate whether the effects of capital requirements on banks' balance sheet adjustments changed after the 2008–09 financial crisis. We find that after the crisis banks placed more emphasis on overall asset de-leveraging. A 1 percentage point increase in capital requirements lowered total asset growth by 14 basis points before the crisis and 20 basis points after the crisis. We also find evidence of a structural change in banks' capital management practices, with banks increasing better-quality, Tier 1 capital significantly more in response to higher requirements after the crisis than they did before the crisis. However, the effects of capital requirements on lending and risk-weighted asset growth both before and after the crisis are similar. Our results suggest that both before and after the crisis, a 1 percentage point increase in capital requirements lowered annual loan (risk-weighted asset) growth by 8 (12) basis points.

Key words: Banking, regulatory capital requirements, bank capital ratios, bank credit supply, macroprudential tools.

JEL classification: D21, G21, G28.

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1. Introduction

This paper provides further insights into the relationship between bank capital and banks' balance sheet management decisions. This link, also known as the *bank capital channel*, has been of ongoing interest to policymakers and academics given the importance of banks in supporting the economy. Of particular interest has been the role that capital requirements play in this link and their implications for bank behaviour and lending supply in particular. This issue has risen in prominence in light of the increased emphasis regulators have placed on actively deploying such requirements to mitigate risks to the economy and financial stability more broadly (see, for example, BCBS (2010a, 2010b) and Bank of England (2015)).

This increased emphasis on the use of capital requirements for macro-prudential purposes means that policymakers, now more than ever, need to have a sound handle on their impacts on economic activity overall. While such impact analyses are not new (see, for example, BCBS (2010a, 2010b), de-Ramon et al. (2012), Bank of England (2013), Brooke et al. (2015)), quantifying the effects on the economy is not straightforward. This is because the effects depend critically on how banks respond to satisfy higher (or lower) capital requirements, and gauging such responses is a challenging task in itself. In principle, there exists a range of possible outcomes. For example, in response to higher capital requirements, well-capitalized banks or banks with ready access to additional sources of capital will be able to satisfy higher requirements without reducing assets or lending or altering the makeup of risk-weighted assets. If, on the other hand, banks actively manage capital ratios to maintain a capital surplus or precautionary buffer ratio (e.g., to reduce the likelihood and cost of breaching regulatory requirements) because they cannot readily (cost-effectively) raise equity to offset the higher requirement, then banks may reduce assets or risk-weighted assets, including lending.

Previous impact studies recognize these challenges and typically fall into one of two strands. The first strand does not attempt to gauge bank responses outright, but instead makes explicit assumptions about bank balance sheet behaviour (e.g., BCBS (2010a, 2010b), Brook et al. (2015), Behn et al., (2016)). These studies then translate such assumed behaviours into effects on the real economy. The second strand estimates banks' balance sheet responses directly and uses these response parameters to calculate ensuing effects on bank lending and capital growth. They then use these results to quantify effects on the real economy (e.g., de-Ramon et al. (2012), Bank of England (2013)).

Our paper is more closely related to this second strand informing how banks respond by looking at past reactions. A key feature of the previous work in this strand is that the responses are conditioned on data from before the 2008-09 financial crisis. It is unclear, however, whether such pre-crisis behaviour is appropriate for impact assessment purposes after the crisis. This is because bank behaviour may have changed in the face of ongoing regulatory reforms and market pressures that have arisen in response to the crisis.

As a step towards investigating this issue, this paper investigates how banks in the UK altered their balance sheets in response to changes in regulatory capital requirements and whether these responses changed after the crisis.[1] We extend the approach developed by Hancock and Wilcox (1993, 1994), who examined how banks in the US responded to the introduction of the Basel I capital requirements, to investigate the role that capital requirements play in affecting UK banks' capital management practices and illustrate the implications for balance sheet behaviour via the *bank capital channel*. In particular, we use a proprietary dataset of individual capital requirements for a large sample of UK banks spanning the period 1989 to 2013 and examine (i) the extent to which capital requirements explain banks' choice of (target) capital ratios and (ii) how banks alter loans, total assets, risk-weighted assets, and capital to deal with changes in regulatory minimums that move them away from their targeted ratios. Investigating (ii), we do not focus on modelling the adjustment process per se, but instead we concentrate on the consequences of such adjustments. This focus allows us to quantify how capital requirements may ultimately influence the levels of lending, assets, risk-weighted assets and regulatory capital at individual UK banks depending on the extent to which a change in requirements moves them away from internal targets. Further, because our dataset spans the crisis, we supplement this analysis by examining whether the banks' target capital management practices and the corresponding adjustment processes observed prior to the crisis hold after the crisis. This aspect of our analysis is a contribution to the literature on the effects of capital requirements.

Consistent with prior research on UK bank capital ratios (e.g., Alfon et al. (2004); Francis and Osborne (2010)), we find that capital requirements are key drivers of banks' *target* capital ratios. More specifically, we find that banks' choice of capital ratio is positively associated with individual capital requirements set by the UK supervisor. This result implies that even when regulatory capital requirements are not binding, they affect banks' capital management practices, consistent with the conjecture that banks act to maintain buffers above regulatory thresholds. Our results indicate that in the short-run (long-run), a one percentage point increase in capital requirements increases total risk-based capital ratios, on average, by around 30 (90) basis points. Even in the long run, then, the results suggest that banks increase capital ratios by less than one for one in response to the higher requirement. We find no evidence to suggest that the sensitivity of UK banks' *choice of capital ratios* to a change in capital requirements has changed after the crisis.

With respect to balance sheet adjustments, we find that capital requirements affect loan, asset and risk-weighted asset growth, albeit modestly. In particular, our results suggest that a one percentage point increase in capital requirements lowers annual loan growth by 8 basis points, annual asset growth by 14 basis points and annual risk-weighted asset growth by 12 basis points. We find evidence suggesting that the effects on lending and risk-weighted assets do not change significantly in the post-crisis period. The impact on asset growth, however, is slightly more pronounced, with reduction in annualized asset growth rising to around 20 basis points for a similar one percentage point increase in capital requirements.

[1] This paper focuses only on evaluating whether response behaviour changed after the crisis and does not investigate the drivers of such change. This issue remains a topic for future research.

When looking at the adjustment of capital levels, we find that the influence of capital requirements on banks' adjustment of capital has changed relative to the pre-crisis period. Our evidence suggests that prior to the crisis, banks tended to focus on raising less-costly, lower quality (tier 2) capital instruments to meet higher requirements. During this time, a one percentage point increase in capital requirements resulted in a 34 basis point increase in the annual growth rate of total regulatory capital, while the impact on the annual growth of tier 1 capital was considerably lower at around 12 basis points. This disparity provides evidence of a 'pecking order' in UK banks' capital adjustment practices, with banks tending to increase better-quality, higher costing tier 1 capital relatively less than overall capital (which includes lower-quality, lower-costing tier 2 elements).[2] Our results suggest that this pecking order behaviour continued after the crisis but that the disparity in choice narrowed, with banks placing more emphasis on responding via tier 1 growth. Specifically, after the crisis, a one percentage point change in capital requirements led to a 52 (42) basis point increase in the annual growth rate of total (tier 1) regulatory capital.

The remainder of the paper is arranged as follows. Section 2 places our study in the context of the extant literature and explains its contribution. Section 3 provides background on UK capital requirements and reviews trends in capital requirements and capital ratios since 1989. Section 4 discusses the data and sample used in examining bank capital and balance sheet behaviour. Section 5 outlines the framework we use to examine the impacts of the bank capital channel and test whether these impacts have changed since the crisis. Section 6 reports results. Section 7 uses the models developed in Section 5 to illustrate how changes in capital requirements affect balance sheet growth rates. Section 8 concludes.

2. Relevant Literature

Previous studies provide evidence on the *bank capital channel* through which shocks that originate from changes in economic conditions or regulatory requirements affect bank behaviour and the real economy. For instance, examining the impact of "substantially heightened" capital requirements for US banks, Kashyap et al. (2010) conclude that in the short- to medium-term, due to greater costs associated with raising new equity finance, banks may opt to comply with the increased capital requirements by slowing the growth of their assets, which could lead to a contractionary effect on lending.[3] They note that this impact could be especially acute if the higher requirements are imposed immediately rather than phased in over a sufficiently long period of time. They go on to point out, however, that the long-run, steady-state impact of shocks to bank capital on loan rates (and supply) is likely moderate.

[2] This result is consistent with the idea that cost-minimizing banks respond to higher regulatory minimums by raising relatively lower-quality, and less expensive, tier 2 capital. Information problems associated with raising better-quality tier 1 equity capital instruments may make it more costly for banks to raise capital through this route (e.g., see Myers and Majluf (1984)).

[3] Their analysis is based on calibrating a model using the well-known Modigliani and Miller (1958) framework, where the primary differences in the costs of equity and debt finance are due to differences in the tax treatment. They do not empirically investigate the impact of higher capital requirements on bank credit supply.

Using data on UK banks, Aiyar et al. (2014) study how banks' credit supply responds to changes in monetary policy and minimum capital requirements set by UK regulators between 1998 and 2007. They find that lending by large banks reacts substantially to capital requirement changes, but not to monetary policy changes, while lending by small banks reacts to both. They also find little evidence of interaction between monetary policy and minimum capital requirements. Bridges et al. (2014) find that regulatory capital requirements affect UK bank groups' actual capital ratios between 1990 and 2011, and that changes in regulatory capital requirements affect bank lending in short term.

Jiménez et al. (2013) analyse how shocks to countercyclical capital buffers, as introduced through Spain's dynamic provisioning regime (unrelated to specific bank loan losses) in 2000 and modified in 2005 and 2008 in response to changes in economic conditions, affected banks' lending supply. They find that individual banks were impacted differently. More specifically, estimates show that countercyclical dynamic provisioning reduces volatility in the credit supply cycle, helping banks sustain lending during bad times. In addition, their results imply that firms dealing with banks holding 1 percentage point (pp) more in dynamic provisioning funds receive 9 pp more in committed credit than when dealing with other banks in the downturn.

In response to the sluggish recovery following the 1990-1991 recession in the US, several researchers developed empirical models to evaluate the effect of bank capital on bank lending. Bernanke and Lown (1991), for example, study the relationship between the loan growth and banks' equity capital to assets ratio for large and small banks in New Jersey during the recession. They find evidence that a shortage of equity capital limited small banks' ability to supply loans. They acknowledge, however, that much of the slowdown was caused by demand factors.

To consider the bank capital channel more directly, Hancock and Wilcox (1993, 1994) use US bank data and estimate models relating changes in bank-level loan growth to measures of loan demand and bank capitalization, defined as the difference between actual and targeted capital levels. The main hypothesis underlying these studies is that banks that are close to their target will have lending that is more sensitive to capital shocks than those banks with relatively more surplus capital. Their approach presumes that capital adjustment costs preclude banks from achieving their targeted levels immediately. The authors find that while a loss-driven shortage of capital might have contributed to the reduction in bank credit supply following the 1990-1991 recession, bank lending was also affected by bank capital shortfalls that might have had little to do with regulatory requirements.

Extending this approach to study balance sheet adjustments more broadly, Hancock, Laing and Wilcox (1995) use quarterly data on individual US banks and estimate banks' dynamic responses to capital shocks in early 1990s. They find that although it took bank capital and securities only one year to adjust to capital shocks (i.e., loan losses that derived from poor economic conditions experienced in the late 1980s and early 1990s), liabilities and most loan categories took two to three years to complete their adjustments. They also find that compared with those in the late 1980s, capital shocks were twice as large and portfolio responses to capital shocks tended to be more rapid in the early 1990s. Their key finding was that capital shocks caused banks with capital shortfalls to contract lending more quickly in the early 1990s than they had in the 1980s, providing some evidence that reactions through this channel can be state dependent.

Following the approach of Hancock and Wilcox (1993, 1994), Berrospide and Edge (2010) study the lending of large US bank holding companies (BHCs) between 1992 and 2008 and find small effects of capitalization on lending. In particular, they explicitly include a measure of bank capital surplus, defined as the difference between a bank's actual capital ratio and its desired or 'target' ratio, in a model of lending growth, controlling for a number of bank-specific and macroeconomic variables. They interpret the coefficient on the capital surplus variable as a measure of sensitivity (elasticity) of lending growth to changes in bank capital surplus. They find that the growth rate of total loans is larger for banks with greater amounts of excess capital. The overall effect, however, is modest: the long-run impact of a capital surplus (shortfall) on total loan growth is to increase (decrease) annualized loan growth by 25 basis points when capital exceeds (falls short of) its target by one percent. Their results suggest more important roles for factors such as economic activity and increased perception of risk by banks.

Applying this same approach to UK bank data between 1996 and 2007, Francis and Osborne (2009) examine the effects of changes in bank-specific capital requirements set by UK supervisors on banks' target capital and the ensuing effects on lending growth. Their first stage capital regression estimates suggest that a one percentage point increase in capital requirements results in a 65 basis point (long-run) increase in internal targets. Using this pass-through rate, they then derive explicit measures of individual bank capital surplus measures, defined as the difference between actual and target ratios and include these models of lending growth. Their estimates also imply relatively small impacts overall: the long-run impact of a capital surplus (shortfall) is to increase (decrease) annualized loan growth by 20 basis points when capital exceeds (falls short of) its target by one percent. Together, these estimates imply that a one percentage point increase in capital requirements (which widens the gap between actual and target by 65 basis points) decreases annualized loan growth by 13 basis points.

They extend this approach to evaluate the effects of capital surpluses (shortfalls) on the growth rates of assets, risk-weighted assets and capital, including total regulatory capital and the subset of better-quality tier 1 capital. For a similar one percent capital surplus (shortfall), the effects on annualized asset and risk-weighted asset growth approximate 24 and 40 basis points, respectively. Their results also suggest that when capital exceeds (falls short of) target by one percent, the annualized growth in total capital falls (rises) by 44 basis points, while the annualized growth in the subset of better quality tier 1 capital decreases (increases) by 32 basis points. The authors point out that the more pronounced impact on total regulatory capital growth is consistent with a pecking order for capital response between 1996 and 2007, with banks focusing first on increasing the least expensive, lower-quality capital when closing the gap with targets.

Maurin and Toivanen (2012) apply this approach to euro area bank data and estimated the impact on banks' assets, lending and security holdings as banks adjust toward their targets. Using data spanning 2005 to 2011 and covering the global financial crisis of 2007 to 2009, they estimated that the closure of one percentage point capital gap would reduce annualized loan growth by around 200 basis points.[4] The impact on securities holdings is found to be between 6 to 7 percentage points, suggesting a pecking order for deleveraging.

These papers provide several broad lessons about the relationship between bank capital and balance sheet behaviour that we attempt to capture in this paper. First, there is evidence that banks respond to changes in capital requirements even when the requirements do not appear to bind. Second, banks do not always alter capital ratios one for one in response to changes in capital requirements. Third, banks take a number of different actions, including altering lending supply, in response to a change in regulatory requirements. Finally, these responses depend on how close firms are to their desired, or internal targeted capital ratios.

Our paper makes a couple of contributions to this literature. First, our emphasis on the *bank capital channel* as a primary way in which regulatory shocks are transmitted to the real economy allows us to consider the dynamic effects of changes in regulatory requirements on banks' desired capital ratios directly. We believe this focus makes the link between capital ratios, capital requirements and balance sheet adjustments more transparent, helping policymakers to understand how to use and interpret the results in impact assessments. Second, we employ a longer time series (1989 to 2013) of data spanning several regulatory regimes and the global financial crisis, which allows us to shed light on bank behaviours over this period. In particular, we formally test for possible structural changes in banks' balance sheet reactions during and after the recent financial crisis. We are unaware any other studies that have specifically looked at whether and how banks' reactions to capital shocks / requirements may have changed since the crisis.

3. Background on UK capital requirements and capital ratios

This section provides background on UK bank capital requirements. It also reviews how UK banks' capital ratios have evolved over the period 1989 to 2013. To provide some context for this study's analysis, it presents some simple descriptive statistics on capital ratios and highlights key movements and differences over time.

3.1. Capital requirements in the UK

Since 1991, capital requirements at UK banks have largely been dictated by the underlying international capital standards as set out under the relevant Basel I, II and III regimes. The purpose of the original Basel Accord in 1988 was to make capital requirements more risk sensitive and commensurate with the degree of risk inherent in banks' balance sheets. The Basel standards require banks meet a minimum ratio of regulatory capital to risk-

[4] This effect is more pronounced than the 30 basis points reduction in annualized lending growth implied by Francis and Osborne (2009) for a similar 1 percentage point gap based on UK data for decade just prior to the start of the crisis: 20 basis points x (1/65) = 30 basis points.

weighted assets, which, until reforms following the financial crisis, equalled 8%. Regulatory capital comprises tier 1 capital, which includes higher-quality, loss-absorbent capital elements such as common equity, and tier 2 capital, which includes subordinated debt and other instruments with capital-like features. Risk-weighted assets, which make up the denominator in the total capital ratio, are calculated using rules set out under the Basel standards. Such rules allocate assets to risk 'buckets' with different weights, reflecting the risk of such asset class. A 100% risk weight, for example, requires banks to hold the full 8% requirement against this asset, while a 50% risk-weighted asset would require 4% capital.

Over time, policymakers made a number of significant refinements to the Basel standards to account for other risks not adequately captured in the original Basel I measures and to allow banks more flexibility in using their own internal models (to determine risk weights and, therefore, the denominator of the capital ratio). In 1996, for example, Basel I incorporated the Market Risk Amendment, mandating that banks hold capital against risks in the 'trading book'. The rule also permitted banks to use their own Value-at-Risk models (subject to supervisory approval) to compute the new capital charge. In 2006, Basel II came into play, amending the framework for establishing risk weights by splitting it into two distinct approaches: the standardized and Internal Ratings Based (IRB) approaches. The standardized approach is effectively an updated version of the original risk 'bucket' approach, while the IRB approach allows banks to use internal models to calculate risk weights on their asset portfolios. Under both Basel I and Basel II, banks could meet these capital requirements with tier 1 capital (mainly common equity, surplus and retained earnings) and tier 2 capital, consisting of subordinated debt and other lower-quality forms of capital, although 50% of the requirements had to be met with higher-quality tier 1 capital.[5]

Another important aspect of Basel II was that it introduced additional, bank-specific Pillar 2 requirements to account for risks not appropriately captured by the underlying Basel rules. In the UK such a supervisory regime of bank-specific capital requirements supplementing the minimum 8% capital requirement has been in place since the early 1990s. Under this approach, which goes beyond the minimum requirements under the Basel standards, UK supervisors undertake firm-specific reviews periodically and, combined with judgments about, among other things, evolving market conditions and the quality of a bank's risk management and systems and controls, establish individual capital requirements for each institution. Prior research finds that these individual capital requirements are highly correlated with capital ratios after controlling for a number of other factors useful in explaining banks' choice of capital ratios (see, for example, Alfon et al. (2005) and Francis and Osborne (2010)). This research suggests that banks tend to hold a buffer over capital requirements, which varies in size depending on bank-level characteristics and macroeconomic conditions. The results also imply that even banks with large buffers are affected by regulatory capital requirements, in the sense that tighter standards will increase the likelihood of supervisory intervention and, in turn, the expected costs of regulatory breach. The extent to which this effects banks' capital management is an empirical question.

[5] The Market Risk Amendment also permitted banks to use tier 3 capital, consisting of subordinated debt, to satisfy capital charges for market risk in the trading book.

3.2. Trends in risk-based capital ratios in the UK

Figure 1 (Panel A) reports the aggregate total risk-based capital ratio and total regulatory requirement for all UK banks for the period 1989-2013.[6] While the overall capital adequacy ratio started this period at a relatively low level compared to the Basel minimum of 8%, it rose rapidly during the early 1990's in the aftermath of the introduction of Basel I.[7] Also of note is a modest rise in the capital ratio in the late 1990's and a persistence of these relatively high levels into the early part of this century, a period characterized by both relatively robust economic conditions and bank earnings. The figure shows a moderate downturn in the capital ratio from 2003 to the end of 2006, a period characterized by a relatively favourable economic climate. Finally, the figure shows an increase in the aggregate capital adequacy ratio beginning in 2008. This upturn is due, in part, to the adoption of Basel II (known as the Capital Requirements Directive in Europe) in 2007 and the generally favourable impact it had on many UK banks (i.e., reducing risk-weighted assets for a large number of banks). This effect was especially pronounced on retail loans, including mortgages, where risk weights fell considerably relative to Basel I levels. It more likely corresponded with significant measures taken both by the UK government and banks themselves to bolster capital ratios in response to the financial crisis and more stringent requirements under Basel III.

While looking at movements in the industry-wide capital adequacy ratio is interesting, aggregate ratios can sometime mask firm-level behaviour. In addition, the diverse patterns reported in Figure 1 (Panel B), which reports the distribution of total risk-based ratios over time, make it difficult to infer whether or how UK banks' capital management practices may have been affected by underlying capital requirements. Our econometric analysis (below) addresses this shortcoming by examining firm-level behaviour explicitly.

To gain more insight into the trends in the capital ratio, we plotted, in Figure 2, the periodic percentage growth in aggregate regulatory capital and risk-weighted assets. As might be inferred from Figure 1 (Panel A), capital grew at a faster rate than risk-weighted assets in the early 1990s, resulting in an increase in the capital adequacy ratio. Capital growth continued to exceed the risk-weighted asset growth throughout the 1990s and contributed to the peak in the capital adequacy ratio in the late 1990s. Beginning in the early 2000s, however, this trend reversed, resulting in the moderate fall in the capital adequacy ratio observed in Figure 1 through 2006. Since the second half of 2008, capital growth has generally exceeded that of risk-weighted assets, contributing to the rise in aggregate capital ratios evident over this period.

[6] The total regulatory capital ratio is computed as aggregate (across all banking groups) eligible regulatory capital divided by aggregate risk-weighted assets. The regulatory capital requirement reflects the aggregate required capital, as determined by the Basel minimums and UK firm-specific add-ons, divided by aggregate risk-weighted assets.

[7] The general upward trend in bank capital ratios during this period is also found in other developed countries as noted in Jackson et al. (1999).

Delving into these movements further, Figure 3 reports the median growth rates in loans, total assets and risk-weighted assets (Panel A) alongside median growth rates in total and tier 1 capital (Panel B). A closer inspection suggests that part of the decrease in risk-weighted asset growth evident during the height of the crisis was accompanied by a decline in asset and loan growth as banks shed assets and reduced lending to satisfy higher regulatory capital requirements and market demands to strengthen capital adequacy overall. Interestingly, the figure also shows that loan growth slowed considerably in response to the introduction of Basel 1 in the early 1990s, wavered around 3 to 5 percent from the mid-1990s to 2006, rose dramatically just ahead of the crisis and fell dramatically after 2007 to levels not seen since the early 1990s. Panel B suggests that the increase in capital over this time was largely due to growth in overall regulatory capital and less from growth in better-quality, tier 1 capital.

4. Data and description of samples

This section describes the data and provides background on the sample of UK banking institutions used in our analysis. Confidential regulatory returns collected by the Bank of England, Financial Services Authority and the Prudential Regulation Authority as the relevant supervisors of UK banks provide the main source of our firm-level data.[8] The data are semi-annual (i.e., twice yearly), spanning the period 1989 to 2013 for banks. Our original sample consisted of 3060 observations covering 164 banking groups for the period from 1989H1 to 2013H2. We use consolidated group-level information rather than data for individual (solo-level) subsidiary banks within a group. This choice reflects the observation that many decisions regarding group activities are taken for the institution as a whole rather than on a subsidiary basis.[9]

In constructing our estimation sample, we made several adjustments to the original sample. First, we excluded institutions with missing observations in total assets, loans, risk-weighted assets, total capital or capital requirements. Second, we adjusted for mergers and acquisitions (M&A) by creating a new banking group after such events, identified using Dealogic data on M&A activity and information obtained on firm histories through desktop analysis. Third, to account for material structural changes not reflected in the M&A database, we also created a new institution whenever both total assets and capital increased or decreased by more than 30 percent.[10] Fourth, we dropped observations when half-yearly capital, asset and loan growth or decay rates exceeded 50 percent. Finally, to minimize the influence of extreme outliers, we winsorized all variables at the 1st and 99th percentiles. Our

[8] More specifically, data come from four different reporting regimes over this time period: Banking Supervision Database 1, 2, 3 for the period up to 2008. From 2008 to 2013, we sourced regulatory data from FSA returns as submitted by banks according to the reporting requirements under BIPRU 12 Chapter 16.

[9] We recognize that capital requirements are set at both the consolidated group level and at the solo (and solo-consolidated) level, which could potentially influence behaviours at both levels. We plan to investigate solo-level behaviour as part of future research.

[10] There are 13 of these new banking groups, which represent approximately 10% of our final estimation sample in terms of total assets. These changes include M&A's such as the Halifax-Bank of Scotland merger into HBOS in 2001, its subsequent acquisition by Lloyds group in 2008 and the NatWest merge Royal Bank of Scotland in 2000.

final sample of banking groups is an unbalanced panel, consisting of 2,435 semi-annual observations encompassing 155 institutions. This sample accounts for over 90 percent of industry assets on average and, therefore, is representative of the UK banking sector overall.

Table 1 reports summary statistics for the variables used in the panel regressions analysing bank behaviour. The table shows that there is a wide variation in total assets, indicating that the sample includes a number of relatively small banks. Roughly a quarter of the sample reflects banks with assets below £600 million, while half of the sample includes banks with assets under £4 billion. The table also shows that banks in the sample tend to hold capital well above regulatory requirements. The average total risk-based capital ratio for the sample approximates 19 percent, well above the average requirement of roughly 11 percent. More than half the sample reflects risk-based capital ratios in excess of 16 percent. Further, while the average trading book to total asset ratio is approximately 10 percent, the median value suggests that more than half the observations do not engage in trading activities and therefore are not subject to capital requirements on that type of activity. Semi-annual growth rates in all balance sheet items average between 2 to 4 percent across the banking groups and over time.

Figure 4 provides more background on individual capital requirements in our sample. It shows that slightly less than half the sample includes cases where institutions experienced a change in capital requirements some time during the period 1990 to 2013. Roughly a quarter involved increases, while around ten percent reflect decreases.

5. Framework for evaluating the impacts of capital requirements

This section describes the approach we take to estimate the effects of capital requirements on banks' balance sheet adjustments. Following previous research (e.g., Hancock and Wilcox (1993, 1994); Berrospide and Edge (2010); Francis and Osborne (2009, 2012); Maurin and Toivanen (2012)), we consider that the main channel through which capital requirements affect bank balance sheet behaviour is through their impact on a bank's overall capital adequacy, as measured by the gap between a bank's actual capital and target capital (i.e., its capital surplus or shortfall). Figure 5 sets out the framework more explicitly, with the basic idea being that banks manage capital to maintain a desired or 'target' ratio above regulatory minimums for a number of well-known reasons.[11] When banks are hit with shocks, including those that derive from changes to regulation, that move them away from such targets, they then take actions to move them back to their desired position.

With this as background, our approach to evaluating balance sheet behaviour involves three steps. First, we specify and estimate a partial adjustment model of bank capital that depends on firm-level characteristics, including individual capital requirements imposed by UK supervisors. Second, we use the parameters from this model to calculate each institution's (unobservable) target capital ratio and percentage surplus or shortfall of actual

[11] See, Alfon et al., (2004) for survey results on why UK banks hold capital buffers and manage ratios to consider regulatory requirements.

capital relative to target. Finally, we use this percentage surplus / shortfall measure to estimate models of loan, balance sheet and capital growth. We detail the method and results for each of these steps below.

5.1. Firm-specific capital surplus (shortfall) measures

The initial step in our approach is to establish the link between banks' choice of capital ratio and regulatory capital requirements. Following previous researchers (e.g., Hancock and Wilcox (1993, 1994), Flannery and Rangan (2006), Berrospide and Edge (2010), Francis and Osborne (2010, 2012)), we use a partial adjustment model between actual and target capital ratios to estimate individual firm-specific capital targets. Because it is not directly observable, the target capital ratio, $k^*_{b,t}$, researchers model it as a function of a vector of control variables, which includes firm-specific and aggregate factors:

$$k^*_{b,t} = \alpha_b + \sum_{n=1}^{N} \zeta_n X_{n,b,t} \, , \quad (1)$$

where X is a vector of N explanatory factors, including individual capital requirements, ζ is a conforming vector of parameters and α_b is a fixed effect for each bank which captures idiosyncractic factors such as business model, management, risk aversion and the mix of markets in which the bank operates. A key behavioural assumption underlying these studies is that banks, subject to both regulatory- and market-based constraints, target optimal capital ratios that depend on the (private) marginal costs and benefits of holding ratios above regulatory minima. Based on the idea that the costs of altering bank capital are prohibitive, preventing banks from moving to their target ratios immediately, we allow that the actual capital ratio, $k_{b,t}$, follows a partial adjustment process:

$$k_{b,t} - k_{b,t-1} = \lambda\left(k^*_{b,t-1} - k_{b,t-1}\right) + \varepsilon_{b,t} \, , \quad (2)$$

where λ is a positive adjustment factor, b indexes banks and t indexes time. In the long run, $k_{b,t}$ converges to the optimum (or desired) $k^*_{b,t}$. If λ equals zero, no adjustment is made, potentially because the adjustment costs outweigh the costs of remaining away from the desired ratio. If λ equals one, then full adjustment is made within one time period of analysis (e.g., six months in our case given that we use semi-annual data). Combining (1) and (2) and rearranging yields the following model of a bank's choice of capital ratio:

$$k_{b,t} = (1-\lambda)k_{b,t-1} + \lambda(\alpha_b + \sum_{n=1}^{N} \zeta_n X_{n,b,t-1}) + \varepsilon_{b,t} \, . \quad (3)$$

We use equation (3) as the basis for estimating the relationship between capital ratios and capital requirements. The long-run parameters, α_b and ζ_n, are derived from the results of estimating (3), taking into account the implied value of the adjustment speed, λ.[12] As discussed in more depth below, we estimate (3) using one lag of each of explanatory variables:

[12] Our analysis implicitly assumes that all firms have roughly the same adjustment speed. We do not attempt to tailor such speeds according to firm size or business model, an area for future research.

$$k_{b,t} = A_b + A_1 k_{b,t-1} + \sum_{n=1}^{N} B_n X_{n,b,t-1} + \varepsilon_{b,t} \ . \quad (4)$$

The long-run effect of each explanatory variable, X_n, is then given by:

$$\zeta_n = B_n/(1 - A_1) \ .^{13} \quad (5)$$

The main capital measure that we consider in deriving our capital surplus/shortfall estimates is the total risk-based capital ratio, since we are most concerned with how firms behave with respect to regulatory concepts of capital adequacy. Our primary explanatory variable of interest in equation (4) is the individual (firm-specific) capital requirement (cr) set by UK supervisors. This requirement is expressed as a percentage of each institution's risk weighted assets. Given that the practice in the UK has been to impose requirements for risks not captured in the international Basel standards, this means that individual capital requirements have always exceeded the Basel minimums. In practice, different capital requirements may apply to an institution's trading and banking books, so we use a weighted average for the overall required ratio.

To control for other possible influences on firms' capital decisions, we include several variables found useful in previous research (e.g., Ediz et al. (1998); Alfon et al. (2004, 2005); Berrospide and Edge (2010); Francis and Osborne (2010)) on the determinants of capital choice. Since many argue that that larger banks may likely face lower overall risk because of greater ability to diversify (e.g., across geographic locations or asset classes) and better access to funding sources (thereby requiring less capital), we include the log of total assets as a proxy for bank size (size).[14] To control for the costs of capital, we include the return on equity (roe) and the ratio of (better quality, higher costing) tier 1 capital to total regulatory capital (tier1).[15] To account for the risk-profile of the institution, we include the ratio of loss provisions to total assets (provision). Provisions reflect a bank's own internal estimate of inherent losses in its asset portfolio. To control for different business models in banks with large trading books (and for differences in the risks between banking and trading books), we include the ratio of trading book assets to total balance sheet assets (tb). The specification also includes bank fixed effects to account for heterogeneity across institutions and period fixed effects to control for external factors that affect all banks' capital management practices.[16] Our benchmark target capital model is as follows:

[13] This follows from noting that A_1 corresponds to (1-λ) in the partial adjustment model.

[14] In particular, we use the time-demeaned value of the log of total assets as a step to avoid spurious correlation between total assets and capital ratios that could arise from non-stationarity of total assets. To calculate time demeaned measure, we first compute the mean log of total assets across all banks in each time period and then subtract this value of the log of total assets for each bank in each period.

[15] Tier 1 capital consists primarily of common stock and retained earnings, but may also include some instruments that are subordinated, have fully discretionary non-cumulative dividends or coupons and have neither a maturity date nor an incentive to redeem.

[16] As discussed below, we also replaced period fixed effects with a proxy for perceptions about overall stock market uncertainty and, therefore, banks' ability to raise equity (i.e., the Chicago Board Options Exchange S&P 500 volatility index (VIX)) and found similar results.

$$k_{b,t} = A_b + A_1 k_{b,t-1} + B_{roe} roe_{b,t-1} + B_{cr} cr_{b,t-1} + B_{tb} tb_{b,t-1} + B_{provision} provision_{b,t-1} + B_{tier1} tier1_{b,t-1} + B_{size} size_{b,t-1} + \lambda_t + \varepsilon_{b,t} \,. \quad (6)$$

5.2. Firm-specific target capital and capital surplus (shortfall) measures

The second step in our approach involves computing target capital ratios and corresponding capital surplus/shortfall measures for each institution in our panel. We calculate target ratios for each bank using the long-run parameters derived (using equation (5)) with the short-run parameters estimated in equation (4) and applying them to our target capital model set out in equation (1). A bank's capital surplus or shortfall in terms of the actual capital ratio relative to this target capital ratio is calculated as follows:

$$Z_{b,t} = 100 * \left[\left(\frac{k_{b,t}}{k^*_{b,t}} \right) - 1 \right] . \quad (7)$$

A negative (positive) value suggests that a bank is below (above) its desired long-run capital target. Described below, to consider the effects of shocks to banks' capital adequacy on bank behaviour, we incorporate this measure directly in models of bank capital and balance sheet management practices.

5.3. Firm-specific balance sheet behaviour

In the third step of our approach, we assess how banks manage their balance sheets in order to maintain target capital ratios. Here, we are specifically interested in evaluating the extent to which institutions adjust capital, lending, assets or the composition of assets (i.e., by shifting among risk-weighted asset classes) to offset deviations arising from a change in capital requirements (cr). To deal with these deviations and close the gap between actual and targeted ratios, banks can take a few different strategies. They can focus on altering the numerator of the ratio by changing capital levels directly (e.g., by issuing equity or decreasing dividend payouts). Alternatively, they may change the denominator, for example, by contracting/expanding lending, selling/investing in assets or shifting among risk-weighted asset classes.

We estimate separate models of balance sheet behaviour. Each reflects the options (j= 1 to 5) available to banks for responding to changes in capital requirements and moving towards internal capital targets. Two focus on the options through the numerator via total regulatory capital (REGK) or tier 1 capital (TIER1K), while the remaining three investigate changes through the denominator via total assets (TA), risk-weighted assets (RWA) or loans (LOANS). In each model the dependent variable is the semi-annual growth rate, calculated as $100*[\ln(BS_{j,t}) - \ln(BS_{j,t-1})]$, where BS_j represents the balance sheet dimension in question. To evaluate the impact of bank capitalization on balance sheet adjustment, we include the capital surplus/shortfall measure, $Z_{b,t}$ (which is a function of capital requirements), as an explanatory variable in balance sheet growth models of the following form:

$$\Delta lnBS_{j,b,t} = \gamma_b + \alpha_j \Delta lnBS_{j,b,t-1} + \beta_Z Z_{b,t-1} + \delta_{PROV} \Delta PROVISIONS_{b,t} + \delta_{CO} CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t} , \quad (8)$$

where $\Delta lnBS_{j,b,t}$ denotes the growth rate of balance sheet dimension j (where j reflects one of each of the five dimensions REGK, TIER1, LOANS, ASSETS, RWA). To control for bank-specific asset risk and credit conditions, we include bank-level net charge-off rates (CHARGEOFF), measured as the ratio of annualized net charge-offs to total assets, and the change in the ratio of loss provisions to total assets (PROVISIONS). The model also includes bank fixed effects to account for heterogeneity across firms and time fixed effects to control for economic (demand and supply) influences.[17]

5.4. Hypotheses development and research questions

Together, these steps highlight the *bank capital channel* through which we expect capital requirements to affect balance sheet behaviour: i.e., their impact on target capital ratios and, in turn, distance from such target positions. As mentioned earlier, previous research on the determinants of UK capital ratios (e.g., Ediz et al. (1998); Alfon et al. (2005); Francis and Osborne (2010, 2012)) finds a statistically significant positive association between capital ratios and capital requirements. These findings imply that target ratios increase (decrease) as capital requirements increase (decrease), everything else constant. This also means that the distance between actual and targeted ratios narrows (widens) given an increase (a decrease) in capital requirements. Finding a statistically significant coefficient on this distance measure, or the capital surplus / shortfall measure, $Z_{b,t}$, in our models of balance sheet growth would establish the link between capital requirements and bank behaviour and provide evidence supporting a *bank capital channel* in the UK. The remainder of this subsection sets out our framework for evaluating whether this link has changed since the crisis.

5.4.1. Has bank behaviour changed during the post-crisis period?

Previous studies find evidence for a bank capital channel in the US and UK. Berrospide and Edge (2010), for example, find a positive and significant relationship between bank loan growth and measures of capital surplus/shortfall using data for a sample of large US bank holding companies. Using UK banking data, Francis and Osborne (2009, 2012) find significant associations between growth rates not only for bank loans, but also for a number of balance sheet elements (assets, risk weighted assets, total regulatory capital and tier 1

[17] We also evaluated a specification that substituted the time-fixed effects with the growth rate in nominal GDP (for both the US and UK) as well as changes in the Consumer Price index and official Bank rate to account for macroeconomic conditions directly and obtained similar results (available upon request).

capital), and surplus/shortfall measures. While both studies provide support for the hypothesized bank capital channel, each is based on data from before the financial crisis, making it difficult to generalize to the post-crisis period. If the relationship between bank behaviour and capital surplus/shortfall measures has changed after the post-crisis period (e.g., because of regulatory reforms and market pressures in response to the crisis), then conclusions based on on parameters conditioned on pre-crisis data could be misleading.

5.4.2. Are banks' capital ratios more / less sensitive to capital requirements?

As a first step towards examining whether behaviour differs in the post-crisis period, we modify our benchmark capital model in equation (6) to test for possible structural changes in the way that banks make decisions about how much capital to hold. Here, we are specifically interested in evaluating whether the sensitivity of bank capital ratios to changes in regulatory capital requirements has changed and, if so, what it implies for long-run capital dynamics. We modify the benchmark capital model as follows:

$$
\begin{aligned}
k_{b,t} = A_b &+ (A_1 + A_2 D_{2007}) k_{b,t-1} + (B_{roe} + B'_{roe} D_{2007}) roe_{b,t-1} \\
&+ (B_{cr} + B'_{cr} D_{2007}) cr_{b,t-1} + (B_{tb} + B'_{tb} D_{2007}) tb_{b,t-1} \\
&+ (B_{provision} + B'_{provision} D_{2007})\, provision_{b,t-1} \\
&+ (B_{tier1} + B'_{tier1} D_{2007}) tier1_{b,t-1} \\
&+ (B_{size} + B'_{size} D_{2007}) size_{b,t-1} \\
&+ D_{2007} + \lambda_t + \varepsilon_{b,t}\ ,
\end{aligned} \qquad (9)
$$

where D_{2007} is a dummy variable equal to one for periods after 2007, the year just before the height of the financial crisis, and zero otherwise. The omitted time period is 1989 to 2007, for which the sensitivity of banks' capital decisions is reflected in the coefficient B_{cr}. Finding a statistically significant coefficient on the interaction $B'_{cr} D_{2007}$ would be consistent with the idea that the sensitivity of banks' capital choice to capital requirements differs in the post-crisis period. A positive (negative) coefficient estimate would suggest that the short-run response of capital choice is more (less) effected after 2007. To understand what this means for the long-term response of capital choice, we need to consider the interaction term ($A_2 D_{2007}$) on the lagged capital ratio. In particular, the long term effects of capital requirements on banks' capital ratios in the post-crisis period is computed as $(B_{cr} + B'_{cr} D_{2007})/[1 - (A_1 + A_2 D_{2007})]$, taking into consideration whether the interaction terms are statistically significant. Finding that both interaction terms are not significantly different from zero would suggest that the long-run responses in the post-crisis period are not different from those in the pre-crisis period.

We also take a second approach to evaluating for structural change which tries to isolate the effects of the crisis period more precisely. The empirical specification is based on Gambacorta and Marques-Ibanez (2011), who evaluated possible structural changes in the period of the financial crisis.[18] We do this by specifying a crisis indicator variable (I_C), which takes a value of one from second quarter 2007 to the fourth quarter 2009 (the period over which we conjecture the crisis lasted) and zero elsewhere, and a post-crisis indicator variable (I_{PC}), which takes a value of one from 2010 onwards and zero elsewhere and interact these terms with the right-hand side variables in the benchmark model. The interaction coefficients in the following model represent the marginal changes during the financial crisis period and during post-crisis period relative to the pre-crisis sensitivity.

$$\begin{aligned} k_{b,t} = A_b &+ (A_1 + A_2 I_C + A_3 I_{PC}) k_{b,t-1} \\ &+ (B_{roe} + B'_{roe} I_C + B''_{roe} I_{PC}) roe_{b,t-1} \\ &+ (B_{cr} + B'_{cr} I_C + B''_{cr} I_{PC}) cr_{b,t-1} \\ &+ (B_{tb} + B'_{tb} I_C + B''_{tb} I_{PC}) tb_{b,t-1} \\ &+ (B_{provision} + B'_{provision} I_C + B''_{provision} I_{PC})\ provision_{b,t-1} \\ &+ (B_{tier1} + B'_{tier1} I_C + B''_{tier1} I_{PC}) tier1_{b,t-1} \\ &+ (B_{size} + B'_{size} I_C + B''_{size} I_{PC}) size_{b,t-1} \\ &+ I_C + I_{PC} + \lambda_t + \varepsilon_{b,t}\ . \end{aligned} \tag{10}$$

This specification allows us to test whether the magnitude of the determinants of banks' choice of capital ratios changed during the crisis and after the crisis period. Of primary interest is determining whether and how the elasticity of banks' capital choice to changes in capital requirements may have changed during the crisis and again after the crisis relative to pre-crisis norms. The coefficients B'_{cr} and B''_{cr} in the above specification measure the short-run, marginal effects of capital requirements during and after the crisis period, respectively. The main test involves evaluating the coefficients in the B_{cr} vector in the above specification. In particular, the short-term effects of capital requirements on banks' choice of capital ratios are expressed as follows:

$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = B_{cr}$, pre-2007,

$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = B_{cr} + B'_{cr}$, during the crisis, and

[18] Examining the role that monetary policy played in influencing bank lending in Europe and the United States during the period 1999Q1 to 2009Q4, Gambacorta and Marques-Ibanez (2011) show that bank-specific factors, including capital adequacy, have a significant impact on the provision of credit. They focus on evaluating whether and how the monetary transmission mechanism may have changed during the 2007-2009 financial crisis. They demonstrate the existence of structural changes during the period of the financial crisis, with one of their main findings being that banks with weaker core capital positions restricted the supply of lending more strongly during the crisis. Their findings point to the need to consider the state contingent nature of the influences on lending behaviour.

$$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = B_{cr} + B''_{cr}, \text{ after the crisis.}$$

The long-run elasticity of banks' choice of capital ratios will depend on the statistical significance of the coefficients on the lagged capital ratio and can be expressed as:

$$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = B_{cr}/(1 - A_1), \text{ pre-2007,}$$

$$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = (B_{cr} + B'_{cr})/(1 - A_1 - A_2), \text{ during the crisis, and}$$

$$\frac{\partial k_{b,t}}{\partial cr_{b,t-1}} = (B_{cr} + B''_{cr})/(1 - A_1 - A_3), \text{ after the crisis.}$$

We evaluate the statistical significance of the interaction terms to assess whether there may have been a structural change in behaviour during and after the crisis periods. Finding that both B'_{cr} and A_2 are not statistically significant would suggest no structural change occurred during the crisis and, therefore, that the long-term sensitivity of banks' capital choice to changes in capital requirements was similar to that before the crisis. We can make similar inferences about the elasticity of banks' capital choice for the period after the crisis by examining the statistical significance of the interaction terms for this period.

5.4.3. Is the sensitivity of balance sheet growth to changes in capitalization different?

We modify our benchmark balance sheet growth model in equation (8) to test for possible structural changes using a similar approach by specifying a dummy variable equal to one for periods after 2007. We do this for each of the balance sheet components, and the key coefficient of interest is the interaction term on our capitalization measure, β'_Z, which measures the marginal effect of capitalization on balance sheet growth after 2007. Finding a statistically significant positive (negative) coefficient would suggest that the bank capitalization has a more (less) pronounced impact on growth after 2007. More generally, finding a statistically significant coefficient estimate would not only provide evidence of a bank capital channel in the post-crisis period, but also suggest that the influences via this channel may have changed relative to the pre-crisis period. The long-run impact of elasticity of balance sheet components with respect to changes in capital requirements for the average bank will also depend on the statistical significance of the interaction term not only on our capitalization measure, $Z_{b,t-1}$, but also on the interaction term on the lagged dependent variable.

$$\begin{aligned} \Delta lnBS_{j,b,t} &= \gamma_b + (\alpha_j + \alpha'_j D_{2007})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta'_Z D_{2007})Z_{b,t-1} \\ &+ (\delta_{PROV} + \delta'_{PROV} D_{2007})\Delta PROVISIONS_{b,t} + (\delta_{CO} + \delta'_{CO} D_{2007})CHARGEOFF_{b,t} \\ &+ D_{2007} + \lambda_t + \varepsilon_{b,t}, \end{aligned} \tag{11}$$

where the coefficient of interest is the interaction term, $\beta'_Z D_{2007}$, on our capitalization variable. Finding a statistically significant coefficient estimate would imply that the short-term elasticity of the relevant balance sheet growth item j to a change in capital requirements is different compared with the pre-2007 elasticity.

We also take a second approach similar to that described above to isolate the effects of the crisis period more precisely. In particular, we define similar crisis and post-crisis indicator variables and augment our baseline balance sheet models. The interaction coefficients in the following model represent the marginal changes during the financial crisis period and during post-crisis period relative to the pre-crisis sensitivity.

$$\Delta lnBS_{j,b,t} = \gamma_b + (\alpha_j + \alpha_j' I_C + \alpha_j'' I_{PC})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta_Z' I_C + \beta_Z'' I_{PC})Z_{b,t-1}$$

$$+ (\delta_4 + \delta_4' I_C + \delta_4'' I_{PC})\Delta PROVISIONS_{b,t-1} + (\delta_5 + \delta_5' I_C + \delta_5'' I_{PC})CHARGEOFF_{b,t-1} \quad (12)$$

$$+ I_C + I_{PC} + \lambda_t + \varepsilon_{b,t} \ .$$

This specification allows us to test whether the effects of the bank capital channel are different during the crisis as well as after the crisis compared with the effects before the start of the crisis. The key coefficients of interest are $\beta_Z' I_C$ and $\beta_Z'' I_{PC}$, which represent the marginal effects of bank capitalization during the crisis and post-crisis periods, respectively. The main test involves evaluating the statistical significance of the coefficients in the β vector in specification (8). The short-term impact on balance sheet component j in response to a change in bank capitalization is expressed by:

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = \beta_Z, \text{ pre-crisis,}$$

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = \beta_Z + \beta_Z', \text{ during the crisis, and}$$

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = \beta_Z + \beta_Z'', \text{ after the crisis.}$$

By contrast, the long-term elasticity will depend on the statistical significance of the coefficients (in the α vector) on the lagged dependent variable. More specifically, the long-run impact is expressed as follows:

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = \beta_Z/(1 - \alpha_j), \text{ pre-crisis,}$$

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = (\beta_Z + \beta_Z')/(1 - \alpha_j - \alpha_j'), \text{ during the crisis, and}$$

$$\frac{\partial \Delta lnBS_{j,b,t}}{\partial Z_{b,t-1}} = (\beta_Z + \beta_Z'')/(1 - \alpha_j - \alpha_j''), \text{ after the crisis.}$$

The statistical significance of the coefficients α_j' and α_j'' will influence the long-run sensitivities of balance sheet component j to bank capitalization as reflected by behaviour during the crisis and after the crisis period. For example, finding that β_Z' and α_j' (β_Z'' and α_j'')

are both not statistically significant would suggest the long-run elasticity during the crisis period (post-crisis period) is not significantly different from the elasticity evident before 2007. Put another way, if no structural changes in the effect of bank capitalization on balance sheet component j ($\beta_z' = \beta_z'' = 0$) or in the autoregressive components ($\alpha_j' = \alpha_j'' = 0$) are detected, the effects of the bank capital channel during the crisis and after the crisis are equivalent to those assessed in examining the sensitivity of balance sheet decisions before the start of the crisis.

5.5. Estimation framework

A possible identification issue that we face in testing whether capital requirements affect banks' capital ratios is that, in principle, banks' capital ratios may impact on supervisors' decisions about setting capital requirements. This could happen, for example, if such ratios are not, in the judgment of supervisors, commensurate with the risk profile of the bank. This issue also extends to our balance sheet growth models where banks' balance sheet management decisions may also impact on their measure of capital adequacy directly.

5.5.1. Estimating capital targets

To estimate the capital target models, we employ dynamic panel data techniques that account for the bank-specific component of the error term. Using a fixed-effects regression, however, may result in biased coefficient estimates in the presence of a lagged dependent variable because that term can be correlated with the disturbance term.[19] This issue may be especially problematic for panel data sets with a limited number (e.g., less than 30) of time periods.[20] We address this problem using the dynamic Generalised Methods of Moments (GMM) procedures developed by Arellano and Bond (1991) and extended by Blundell and Bond (1998). These procedures, which introduce instruments in levels and first differences for the lagged dependent variable, allow us to derive consistent and unbiased estimates of the relationship between capital requirements, bank-specific characteristics and capital ratios.[21]

The GMM estimator ensures efficiency and consistency provided that the models are not subject to serial correlation of order two and that the instruments used are valid (which we check using the Hansen test). We use the system GMM procedure and the instruments (in levels and difference form) as suggested by Blundell and Bond (1998). Under this approach, exogenous variables, transformed in first differences, are instrumented by themselves, while endogenous regressors (including capital ratios) are transformed in first differences and instrumented by their lags in levels. Taking the advice of Roodman (2007), we collapse the instrument matrix so that there are not unique instruments for each time period and we restrict the number of lags (to two) of the dependent variable in the instrument set. This is done to avoid proliferation of the instrument set that can cause problems with the diagnostic statistics and with the process of weighting the moments. We calculate long-run coefficients

[19] See Nickell (1981) for a discussion of this short-panel bias and how it arises.
[20] See Judson and Owen (1999) for more detail.
[21] We employ the implementation of this estimator in Stata by Roodman (2006).

using the coefficient on the lagged dependent variable and their standard errors using the delta method.[22]

5.5.2. Estimating balance sheet growth

To estimate the balance sheet growth models, we followed a two-step approach. In the first, we assume that the partial adjustment process characterizes each dimension of balance sheet growth and estimate equation (8) using GMM. In the second step, we review the output for each model, and focusing on the coefficients on the lagged dependent variables, we then determine whether the partial adjustment process was an appropriate characterization for that dimension of balance sheet growth. Where we find that the growth in a balance sheet dimension was not significantly correlated with its own lags, we conclude that the partial adjustment process was not appropriate. In these situations, we exclude the lagged dependent variables and subsequently estimate balance sheet growth using a fixed effects estimator.[23] Discussed in more depth below, this process produced two models based on the fixed-effects estimator (for loan and RWA growth) and three models based on the GMM estimator (assets, total regulatory capital and tier 1 capital).

6. Empirical results

6.1. Determinants of bank capital ratios

This section reports the results of our analysis of the determinants of bank capital ratios and tests of possible structural change. It also discusses the measure of bank capitalization (i.e., bank capital surplus or shortfall relative to target) that we use in our subsequent analysis of balance sheet behaviour.

Table 2 presents the short- and long-run coefficients from two specifications of our preferred target capital model conditioned on the entire sample period 1989 to 2013. The only difference between the models is that the second set of results reported in the final two columns includes time period effects. Except for the coefficient on our measure of bank-level expected asset risk, as captured by the ratio of provisions to total assets (provisions), all coefficients are significant, with signs consistent with expectations. The results show a negative association between banks' capital ratios and return on equity (ROE), suggesting that capital ratios are lower at banks with higher ROEs. To the extent that ROE proxies banks' cost of capital, this negative relationship is consistent with banks minimizing capital costs. We also find a negative association between capital ratios and size, implying that larger banks tend to hold relatively lower capital ratios on average. This finding is consistent with previous research on the determinants of UK bank capital ratios (e.g., Alfon et al., 2005; Francis and Osborne, 2010) and with the notion that larger banks may be better diversified both geographically and across different asset classes, allowing them to hold lower capital

[22] See Greene (2003), p. 70.
[23] We choose fixed effects estimation after conducting Hausman tests to confirm preference for this method over random effects.

ratios overall. It may also be consistent with larger banks having relatively easier access to capital markets, dampening the need to hold higher capital ratios routinely.

Table 2 also shows a significantly positive association between capital ratios and trading book activity (tb). This result indicates that targeted capital ratios increase (decrease) as banks' involvement in trading activity increases (decreases). The results further confirm a positive relationship between capital ratios and our measure of the quality of capital (tier1), indicating that banks that rely on a relatively larger share of higher-quality -- and ostensibly higher-costing -- tier 1 capital hold higher risk-based capital ratios overall. This finding is consistent with the notion that such banks find it more costly to raise capital, and, therefore to reduce the expected costs of raising new capital, they hold higher capital buffers. The findings also show that the association between capital ratios and market volatility (VIX) is positive, implying that capital ratios are higher (lower) as market sentiment worsens (improves). This result is consistent with the conjecture that banks build buffers during periods of higher market uncertainty.

Of primary interest is the relationship between capital ratios and capital requirements (cr), which the results show is positive and statistically significant, both in the short-run and long-run. The positive association suggests that banks respond to higher (lower) requirements by increasing (reducing) their actual ratios. More specifically, our point estimates indicate that the pass-through of a change in capital requirements into capital ratios is, on average, around 30 percent in the short-run and 90 percent in the long-run.[24]

The coefficient on the lagged capital ratio implies a relatively quick adjustment of capital ratios to target. Based on the full estimation period 1989 to 2013, our estimated average speed of adjustment is around 64 percent per year.[25] Our adjustment speed is slightly above those estimated by other researchers using US data that covers the earlier periods from our study. Berrospide and Edge (2010) and Berger et al. (2008), for example, estimate average adjustments speeds in the range of 28 to 40 percent annually, while Flannery and Rangan (2008) estimate higher speeds of around 50.[26]

6.2. Analysis of structural change in the determinants of bank capital ratios

This section discusses results of our tests examining whether and how the determinants of banks capital ratios may have changed compared with behaviours exhibited prior to the start of the crisis in 2007. Here we are mainly interested in understanding whether sensitivity of banks' choice of capital ratios to capital requirements has changed. Significant

[24] The long-run estimate is computed as 0.29/(1-0.67).

[25] This is calculated as the adjustment speed (λ=1–0.68), multiplied by 2, to translate the six-month adjustment rate into an annual rate.

[26] Our relatively faster adjustment speed may, in part, reflect the UK regulatory practice of informing banks of their individual capital requirements several months in advance of the date on which they take effect. This practice, as a result, provides banks with some lead time in which to make adjustments prior to the date on which the new requirements must be met. In addition, changes to individual capital requirements and the date on which they go into effect take into consideration planned changes to bank balance sheets and capital levels. This feature of the UK regime may also contribute to the apparent rapid pace at which capital ratios adjust in this country.

changes to bank regulation and heightened market pressures after 2007 in response to the crisis make it reasonable to believe that this sensitivity may be different.

As part of our investigation, we compared parameters estimated based on our full sample period (1989H2 to 2013H2) with those using sub-samples (1989H2 to 2007H1) and (2009H2 to 2013H2). We exclude data from the crisis period (from 2007H1 to 2009H2) because this period was characterized by several unusual regulatory actions as well as reporting issues that raised questions about the reliability of regulatory report information during this period. Table 3 shows the long-run parameters for the target model for the whole sample period and for the pre- and post-crisis periods. Focusing on the coefficient on capital requirements, we see that the point estimates in the post-crisis period are slightly lower, decreasing from 0.98 to 0.86. This result suggests that while capital requirements continue to be a key driver in banks' capital management practices overall, the sensitivity of capital targets to capital requirements may have diminished only modestly in the aftermath of the crisis.

To explore this possibility more formally, Table 4 reports results of estimating our benchmark model modified to take into account possible structural change after 2007 (i.e., as set out in equation (9)). Focusing on the long-run, we see that with the exception of the coefficient on our provision measure, the signs on all of the coefficient estimates are similar in the pre- and post-2007 periods. The association between capital ratios and bank size and returns is negative in both periods. Again, these findings are consistent with the idea that larger banks and banks with higher costs of capital (as proxied by roe) hold lower capital ratios.

The results also show positive relationships between capital ratios and our measure of capital quality (tier1), trading activities and capital requirements in both periods. A closer examination of the interaction coefficient on the capital requirement variable indicates that it is not statistically significant, providing some evidence of an absence of structural change between capital ratios and capital requirements after 2007. This finding provides some support for believing that our benchmark model based on the full sample timeframe is not unreasonable for quantifying the effects of capital requirements on capital ratios.

Still, the crisis period included several unprecedented interventions by the UK government and market pressures to deal with concerns about capital adequacy that arguably may have resulted in more material changes during this period. Whether these factors resulted in permanent (structural) changes in the drivers of banks' capital choice is at the heart of the analysis of this section. Table 5 reports the GMM regression estimates of equation (10) for the determinants of UK banks' target capital ratios using the full estimation sample timeframe 1989 to 2013, which accounts for potential structural changes in behaviour during and after the crisis period, where we have defined the crisis period as spanning from the second half of 2007 to the end of 2009 (i.e., 2007H1 to 2009H2) and the post-crisis period as spanning from the end of 2009 to 2013.

Again, focusing on the long-run estimates, we find that, with the exception of the provision measure, the associations between capital ratios and each of the underlying drivers of capital choice are similar across the three time periods. The negative relationships between capital ratios and bank size and bank returns continue to hold in this analysis and over the three distinct periods. The positive associations between capital ratios and tier1, trading book activities and capital requirements also remain in this analysis and hold across the three periods. And while the point estimates on capital requirements indicate that the long-run elasticity of banks' choice of capital ratios to changes in capital requirements became less pronounced after the crisis (i.e., 0.92 after the crisis versus 1.06 before the crisis), closer inspection reveals that each coefficient is not significantly different from one. This result provides some additional evidence that no material structural change in the elasticity of banks' capital management practices with respect to capital requirements has occurred in the period after the crisis.

6.3. Bank capitalization

Because we cannot definitively conclude that banks' capital management practices changed in the period after the crisis, we rely on computing our measure of bank capitalization based on estimates from our benchmark target capital model as set out in equation (6). We use the coefficient estimates reported in Table 2 to calculate a time series for each banks' target capital ratio, $k^*_{b,t}$. We then use these target capital ratios to construct measures of banks' capitalization, i.e., capital surplus or shortfall, denoted by $Z_{b,t}$, calculated as deviations of actual capital ratios relative to target ratios (as in equation (7) above).

Figure 6 plots the average actual and target capital ratios over our estimation period. Differences between the actual and target ratios appear quite pronounced and persistent in some time periods. In the early to 1990s, for example, capital targets were higher as banks were likely responding to higher requirements under Basel I. During the mid-1990s, actual average capital ratios exceeded targets, which exhibited a sharp increase around 1996 at about the time the Market Risk Amendment was introduced and raised capital requirements on trading activities. From 2008 to 2012, average bank capital targets exceeded actual ratios as capital requirements continued to increase and regulatory emphasis on higher-quality tier 1 capital mandates heightened.

6.4. Bank balance sheet adjustments

To gauge the effects of bank capitalization on loan growth, we include our estimates of bank capital surplus/deficit, as represented by $Z_{b,t}$, in regressions of loan growth. This approach is similar to the approach taken by previous researchers to examine the link between bank capital and loan growth, e.g., Hancock and Wilcox (1993, 1994), Berrospide and Edge (2010), Francis and Osborne (2009, 2012) and Maurin and Toivanen (2012), while accounting for macroeconomic conditions. We also extend the analysis to evaluate the impact on balance sheet behaviour more broadly.

Equation (8) sets out the benchmark panel regressions we use to model the growth in balance sheet dimension j (i.e., where j represents loans, total assets, risk-weighted assets, total regulatory capital and tier 1 capital) as a function of its own lags and bank-specific characteristics to control for the change in credit quality and risk profile of the institution: the change in provisions ($\Delta PROVISIONS_{b,t}$) and net chargeoff rates ($CHARGEOFF_{b,t}$). Finally, we include our the measure of bank capitalization ($Z_{b,t}$), our main variable of interest.

6.5. Analysis of the dynamics of balance sheet growth

In using equation (8), which includes lagged dependent variables, as our benchmark model, we implicitly assume that balance sheet growth follows a partial adjustment process, similar to that underlying the target capital model. While there are a number of technical and institutional rigidities, contractual arrangements and adjustment costs that may justify modelling balance sheet growth as a dynamic, autoregressive process, the choice remains an empirical question. We evaluate this issue in two steps. First, we estimate equation (8) including lags of the relevant dependent variable. Here the idea is that growth may be explained not only by bank capitalization and individual bank characteristics, but also by the persistence effect of past growth trends. We do this by introducing two lagged values of growth in each equation. Given the frequency of our panel dataset, this approach means testing a persistence that lasts six months or one year. Second, we examine the significance of the coefficient estimates on the lags and determine whether growth in balance sheet dimension j is better characterized by a dynamic, autoregressive process or a non-dynamic process, independent of previous growth.

Table 6 reports the estimated persistence (and significance) using GMM estimation for the pre-crisis period (1989-2007) and full-sample period (1989-2013) separately using different lag specifications.[27] It shows that not all models include a significant persistence term. In particular, loan growth and risk weighted assets growth show no significant persistence term.[28] Output for models of growth for total assets, total capital and tier 1 capital, on the other hand, shows that the persistence coefficients are significant, but relatively small. This analysis suggests that growth in total assets, total capital and tier 1 capital may be better characterized by a dynamic, autoregressive process (e.g., using a GMM estimator), while growth for loans and risk weighted assets may be better reflected by a non-dynamic process (e.g., using a fixed effects estimator).

Table 7 reports the long-run coefficients from our preferred models based on data for the full timeframe. The results show positive and statistically significant associations between growth in loans, assets and RWA and our measure of bank capitalization ($Z_{b,t}$). The findings suggest that lending and balance sheet growth overall is greater at banks with excess capital (above desired targets). This results also implies that lending and balance sheet growth falls in response to shocks, including those emanating from a change in capital requirements, that move firms away from their target ratio (i.e., that narrow our measure of bank capitalization). The table also reports a negative association between bank capitalization and growth in total and tier 1 capital. This finding is consistent with the idea that capital growth is lower at banks

[27] The underlying estimation output associated with all of the balance sheet growth models reflected in Table 6 is available upon request.

[28] This finding holds in other versions of this specification which include time-period interactions.

with excess capitalization. The coefficient in the total capital growth model is significantly higher (in absolute terms) than that in the tier 1 model, suggesting that banks tended to adjust better-quality, tier 1 capital less than other, lower-quality (tier 2) capital elements when adjusting to a shock to capitalization, such as a change in capital requirements. During this period, changing tier 2 was less expensive than issuing tier 1 capital, so this result is consistent with the idea of banks choosing the least costly way to respond to changes in capital requirements.

6.6. Analysis of structural change in balance sheet growth

To examine whether and how the effects of bank capitalization may have changed during and after the crisis, we estimated two versions of our balance sheet adjustment models. The first, set out in specification (11), attempts to gauge the marginal effects after 2007, the year in which many argue the crisis started. In particular, we evaluate the statistical significance on the interaction terms with the 'Post-2007' dummy variable to determine if a structural break in balance sheet behaviour occurred. The second approach, set out in specification (12), tries to isolate the effects during the crisis more explicitly, by including indicator variables for the crisis period (defined as spanning from the second half of 2007 to the end of 2009) and the period after the crisis (from the beginning of 2010 to the end of our sample period, end-2013). Again, we focus on evaluating the statistical significance of these interaction terms to draw conclusions about structural change.

Table 8 reports Wald tests of significance for all of the interactions terms in each of the separate specifications.[29] Because the dynamics of balance sheet growth potentially differ across the five balance sheet dimensions under consideration (as discussed in the previous section), the table highlights the most relevant test for each in bold typeface. The test results show that, with the exception of the model for loan growth, all of the other balance sheet growth models appear to have undergone structural change after 2007 (see top two rows reporting the Post 2007 results). These findings would suggest, then, that it might not be unreasonable to use the pre-2007 relationships to gauge the effects of capital requirements on loan growth after 2007. To quantify the effects on the other four dimensions of balance sheet behaviour (assets, risk-weighted assets, total capital and tier 1 capital), however, it may be more appropriate to rely on parameters that consider the structural change after 2007.

The period from 2007 to 2013 covers not only the Great Financial Crisis, but also a number of regulatory actions and market pressures that likely affected behaviour within this period. As a result, considering the entire post-2007 period could mask subtle changes that may have occurred during this period. Indeed, the results in Table 8 suggest, in general, balance sheet behaviour changed after 2007, although in some instances this change was mostly concentrated during the crisis (i.e., loan growth). The findings have implications for how policymakers should think about using these relationships (and the underlying parameters) to estimate the effects of capital requirements.

[29] Specifically, the null hypothesis under this test is that all of the interaction terms are jointly equal to zero, implying no structural change. Full estimation output underlying these tests is available upon request.

6.7. Analysis of the sensitivity of growth to changes in capital requirements

While the Wald tests provide evidence that balance sheet behaviour may have changed after 2007, and, in particular, after the height of the crisis, it is not clear whether the relationships between growth and capital requirements (through the capital surplus / deficit measure, Z_{it}) have changed, which is an issue at the heart of this study. To shed light on this this issue, we rely on results from our preferred estimators (GMM or fixed effects) reported in Table 9 and focus on examining the interaction terms on the capital surplus measure, Z_{it}, for each growth model. The top three rows of this table report the coefficient estimates on the interaction terms from the extended balance sheet growth models modified to test for changes during and after the crisis. The results more clearly delineate whether and how the short-term impact of capital requirements (through the capitalization channel) may have changed in the post-crisis period. The results suggest that after the crisis, loan growth became less sensitive to changes in capital requirements (and shocks to capital more generally). A closer look at the coefficients also indicates that the sensitivity of tier 1 capital to changes in requirements became more pronounced in the post-crisis period. This finding is consistent with the idea that, after the crisis, banks placed greater emphasis on raising better-quality, tier 1 capital in response to shocks to capitalization that derive from, say, higher capital requirements.

In the next several sections, we discuss the main highlights from our preferred growth models and the effects of capital requirements and their implication for policy. We focus our discussion on the short-run parameters reported in Table 9.1 which indicate whether and how growth relationships changed during and after the crisis period.[30]

6.7.1. Analysis of loan growth

For total loans there is a positive and statistically significant coefficient on capital surpluses, indicating that the growth rate of loans is larger for banks with greater amounts of excess capital. The effects, however, are relatively modest. The long-run impact of a capital surplus (shortfall) on total loan growth is roughly to increase (decrease) annualized loan growth by 0.10 pp when capital exceeds (falls below) its target by 1 percent. Given the 90% pass-through of capital requirements to capital ratios, a 1 pp increase in capital requirements implies a 0.09 pp drop in annualized loan growth in the long-run (based on parameters conditioned on data both before and after the crisis). This effect became more pronounced during the crisis when a similar increase in capital requirements lowered loan growth by around 0.31 pp (i.e., 0.17 x 2 x 0.9). The interaction term in Table 9.1 suggests, however, that the sensitivity of loan growth to capital requirements after the crisis was similar to that in the pre-crisis period.

6.7.2. Analysis of asset growth

Turning to total assets, we find positive and statistically significant long-run coefficients on capital surpluses for both the pre- and post-crisis periods. This indicates that the growth rate of assets is larger for banks with greater amounts of excess capital, though,

[30] For completeness, Table 9.2 reports the corresponding long-run coefficients from our preferred estimators.

like the effects on loan growth, the effects on overall asset growth are moderate. The long-run impact of a capital surplus (shortfall) on total asset growth is roughly to increase (decrease) annualized asset growth by 0.14 pp (i.e., 0.07 x 2) when capital exceeds (falls below) its target by 1 percent. The interaction terms for both the crisis and after-crisis period both suggest that the sensitivity of balance sheet growth remained similar to that exhibited before the crisis.

The results also show that credit conditions played significant, but limited, roles in determining asset growth. More specifically, a 1 pp increase in the provisions ratio lowered annual asset growth by just over 5.0 pp (i.e., -2.6 x 2) prior to the crisis, while a similar increase in chargeoff rates lowered asset growth by about 1.0 pp (i.e., -0.49 x 2). The coefficients on the interaction terms suggest that these effects remained similar during and after the crisis.

6.7.3. Analysis of risk-weighted asset growth

For risk-weighted assets, we find positive and statistically significant short and long-run coefficients on capital surpluses for the pre-crisis period. This implies that growth in risk-weighted assets is larger for banks with greater amounts of excess capital relative to internal targets. This effect, however, is relatively modest: the impact of a capital surplus (shortfall) on risk-weighted asset growth in the pre-crisis period is roughly to increase (decrease) annualized RWA growth by 0.12 pp (i.e., 0.06 x 2) when capital exceeds (falls below) its target by 1 percent. The interaction terms suggest that the sensitivity of RWA growth is similar in the crisis and post-crisis periods. Combining this with the 90% pass through rate, a 1 pp increase in capital requirements implies a reduction in annualized RWA growth of around 0.10 pp.

The results also suggest that credit conditions played a significant role in affecting the growth in risk weighted assets. For example, prior to the crisis, a 1 pp increase in the provision ratio lowered annualized RWA growth by just under 5.0 pp (i.e., -2.3 x 2) in short and long-run. This effect reversed in the crisis period, when a similar increase in provisions resulted in around an 18 pp (i.e., 9.1 x 2) increase in RWA. Changes in net charge-offs also affected RWA growth, but to a lesser extent, with a 1 pp increase lowering annual RWA growth by approximately 1.4 pp (i.e., 0.7 x 2). This effect, however, remained unchanged during and after the crisis period.

6.7.4. Analysis of total regulatory capital growth

For total regulatory capital, there is a negative and statistically significant association with capital surpluses. This indicates that the growth in total regulatory capital is lower for banks with greater amounts of excess capital relative to internal targets. The impact of a capital surplus (shortfall) on total regulatory capital growth is to decrease (increase) annualized total regulatory capital growth by roughly 0.3 pp (i.e., 0.17 x 2) when capital exceeds (falls below) desired amounts by 1 percent. There is evidence that this effect was greater after the crisis at around 0.50 pp (i.e., 0.26 x 2) for a similar relative capital position. Using the 90% capital pass-through of requirements to actual ratios, we compute that a 1 pp increase in capital requirements leads to about a 0.25 (0.45) pp increase in total regulatory capital based on the pre-crisis (post-crisis) response rate. This result indicates that after the crisis, banks increased their emphasis on raising capital to deal with shocks to capitalization that derived from changes in capital requirements.

6.7.5. Analysis of tier 1 capital growth

When evaluating the growth in tier 1 capital, which reflects the subset of overall regulatory capital that includes the highest-quality, loss-absorbent capital instruments including equity, we find a negative association with capitalisation. This indicates that the growth in tier 1 capital is lower for banks with greater amounts of excess capital relative to internal targets. Before the crisis, a 1 pp increase in capital requirements was associated with around a 13 pp (i.e., 0.07 x 2 x 0.9) increase in annual rate of growth in tier 1 capital. After the crisis, however, a similar increase in requirement resulted in around a 38 pp (0.21 x 2 x 0.9) increase in annualized tier 1 growth. This change in sensitivity compares well above the impact pre-crisis when capital requirements were relatively toothless in prompting banks to increase better quality capital. The change in behaviour is consistent with the recent shift in regulation mandating that qualifying regulatory capital comprise higher proportions of better-quality capital elements.[31] It also provides evidence of a change in the 'pecking order' of banks' capital adjustment practices.

6.8. Additional tests and robustness checks

We conducted several robustness checks that leave our main conclusions unchanged. Table 10 summarizes the findings from these additional checks.[32]

First, we considered the possibility that the effect of capital on balance sheet growth could vary across the economic cycle. There is a chance that if this is the case, then the effects of capitalization on balance sheet adjustments could be dampened by estimating the relationship between growth and capitalization over a long time frame as we do in this study. To test this conjecture, we interact the coefficients on our capitalization measure, Z_{bt}, in equations (11) and (12) with real GDP growth to determine whether the magnitude of this effect increases during more trying conditions. We find that the interaction terms are not statistically significant for asset, total capital and tier 1 capital growth models, suggesting that the size of the effect of bank capitalization (and capital requirements) is not different in downturns versus upturns (see lines 1 and 2 of Table 10 for conclusions). We find that the interaction terms in the loan and RWA models, however, are negative and marginally significant implying that impact of capital requirements on lending and RWA growth is marginally lower (higher) during favourable (unfavourable) economic conditions.

We also considered the prospect that bank capitalization could have different effects on bank behaviour depending on the size of the bank (where we conjecture that size may be related to the ease with which banks can tap capital markets and to market perceptions about systemic). To test for this possibility in the full-sample period, we interacted the bank

[31] See, for example, BCBS (2011).
[32] Details underlying such tests are available upon request.

capitalization measure, Z_{bt}, with a dummy variable set equal to one if a bank had assets in the 90th percentile in our sample each period. None of the interaction terms is statistically significant, suggesting that large banks do not behave differently from small banks in response to higher capital requirements (see lines 3 of Table 10 for conclusions).

Finally, we investigated the chance that capital requirements could have non-linear effects on balance sheet growth. We did this indirectly by adding a quadratic term of our bank capitalisation measure, Z_{bt}, to each of the five growth regressions. We found that the term was statistically significant in the RWA and total capital growth regressions only. As Table 10, line 4 shows, in the RWA growth model, the sign on the quadratic term is negative, suggesting that the marginal impact on RWA growth diminishes as bank capitalization increases. This result also implies that effects of capital requirements on RWA growth diminish (amplify) as bank capitalization climbs (falls). The table also shows that in the total capital regressions, the sign on the quadratic term is positive, implying that capital requirements have a smaller (larger) impact on capital growth as bank capitalization increases (decreases).

7. Illustrative impact assessment

The empirical results in the previous section provide evidence on how banks adjusted their balance sheets in response to changes in credit conditions and individual capitalization (i.e., surplus or deficit relative to target). Combining these results with the estimates from the target capital model in Equation (6), we can measure the impacts of a change in capital requirements on each of the balance sheet elements considered above. In this section, we use the models to evaluate effects of a policy experiment involving the introduction higher regulatory minimums during a credit boom.

Such *ex ante* impact analysis may be of interest to macroprudential (as well as microprudential) policymakers as they consider the costs and benefits of deploying countercyclical capital tools to deal with emerging risks in the economy.[33] For example, The Bank of England's Financial Policy Committee (FPC) signalled its intention to set the UK countercyclical capital buffer rate in the region of 1% in a standard risk environment.[34] In March 2016, consistent with the FPC's assessment of the risk environment, and its intention to move gradually, the FPC decided to increase the UK countercyclical capital buffer rate from 0% to 0.5% of risk-weighted assets.

In this section, we use our panel regression results reported in Table 2 for the target capital model and Table 9.1 for our balance sheet growth models to estimate the impact of a

[33] In December 2010, the Basel Committee on Banking Supervision published Basel III: A global regulatory framework for more resilient banks and banking systems which presents the details of global regulatory standards on bank capital adequacy and liquidity, including a countercyclical capital buffer. The countercyclical capital buffer aims to ensure that banking sector capital requirements take account of the macro-financial environment in which banks operate.
[34] See Bank of England (2015).

countercyclical capital policy similar in spirit to that announced by the FPC in early 2016.[35] Specifically, we quantify the effects of a series of countercyclical capital requirements introduced during a period of elevated credit risk. As a starting point, we assume that the regulator introduces five successive 0.5 percentage point increases in capital requirements from mid-2017 to mid-2019 to counteract emerging risks in the economy. We also presume that banks respond in the same way as we have estimated.

To illustrate the effects on balance sheet and capital growth over this period, we apply these response rates to information on individual bank balance sheets and capital positions as of year-end 2013, our most recent set of financial data for UK banks.[36] In particular, we first use information on individual banks' capital ratios and requirements along with the 90% pass-through rate applied to the additional countercyclical capital charge to calculate new target capital ratios for each bank in our sample. We then calculate how this changes each bank's capitalization (Z_{bt}) relative to what it would be without the new countercyclical charge. We then use the implied change to evaluate the impacts on balance sheet and capital growth using the response rates reported in Table 9.1, showing how banks reacted before, during and after the crisis. We then recalculate the stocks of loans, assets, RWAs, total capital and tier 1 capital in each successive period using the adjusted growth schedule, allowing the resulting change in the capital ratio to feed back onto the calculation of bank capitalization (Z_{bt}). This is done for each period over which the countercyclical charges are raised.

The immediate effect of each increase in countercyclical capital requirement is to dampen bank capitalization (Z_{bt}), which, implicitly, drives up capital targets overall. Our simulations show how banks take actions to close the gap between actual and target capital opened by the new countercyclical charge. Since there is some evidence that UK banks' actions differ after the crisis, we show simulations based on pre- and post-crisis response rates.

Table 11 reports the pro-forma impacts of the additional capital charges on balance sheet and capital growth. The table shows that both before and after the crisis, banks reduced lending, assets and risk-weighted assets together with actions to raise capital to deal with shocks to capitalization. Prior to the crisis, these actions focused largely on lowering risk-weighted assets and raising lower-quality, tier 2 capital elements in response to higher capital requirements (i.e., the pre-crisis growth in total capital exceeds that of tier 1 capital). The simulation results show, however, how this behaviour changed notably after the crisis. After the crisis, banks placed greater emphasis on raising better quality, tier 1 capital In particular, the average annual growth rate in tier 1 capital (relative to the baseline case where no additional requirements are introduced) is around 32% based on post-crisis behaviour, which is considerably higher than 9% based on pre-crisis response behaviour.

[35] This "what if" analysis is only an indicative, partial equilibrium analysis, since it abstracts from the possible feedback effects from the real economy to bank balance sheets. It also does not consider the influence of competition and market structure on bank balance sheet adjustments.
[36] In practice, one would want to use financial data from 2017.

Figure 7 illustrates these effects and how these differences evolve over time. The simulation results reflect the median impacts on growth across all UK banks in our sample. The figure shows that the effects on lending growth are relatively modest, with growth rates falling to less than 1% below the baseline in the long-run based on either pre- or post-crisis behaviour. The figure delineates better the main differences between pre- and post-crisis behaviour: i.e., a shift towards a greater emphasis on raising capital – and, in particular, higher-quality tier 1 capital – in response to higher capital requirements. Furthermore, it also shows that banks continue to reduce RWAs to help satisfy higher capital requirements, though to a lesser degree than before the crisis.

While these results shed some light on how firms may react to a permanent increase in capital requirements, there are several caveats worth highlighting when using the findings. First, we find evidence suggesting that the effects of bank capitalisation, and, therefore, capital requirements by design, may have changed since the crisis. These differences are especially pronounced with respect to the sensitivity of capital growth and suggest that policymakers will need to make judgments about which set of reaction parameters to use in their impact assessments.

Second, our estimates are based on the historic UK capital regime that, in general, imposed relatively small changes in capital requirements to some individual banks. The impact of a large and coordinated increase in capital requirement across the industry may well be different.[37] Our estimates suggest that, in the long run, the pass-through of a change in capital requirements into the capital ratios is around 90%. Given a sizeable increase, however, this pass-through rate may mean that banks could end up with low buffers, potentially increasing the likelihood of a capital breach. It may be the case, then, that banks, especially under the new regime that limits distributions of capital depending on banks' capital headroom relative to minimum requirements, may pass-through larger proportions, possibly approaching 100%. If this happens, this could lead to more sizeable balance sheet adjustments. That said, we do not find definitive evidence of a structural change in our model of the determinants of capital choice based on data spanning 1989 to 2013, which covers the period when higher requirements under Basel III were finalized and bank expectations of such likely solidified.

Third, the results do not capture possible effects on the real economy, e.g., the effects on GDP due to the reduction in loans and mortgages, and their subsequent feedback effects – from the demand side – on banks' balance sheets. This is an important consideration as the explicit aim of introducing such a countercyclical capital requirements is to rein in a burgeoning credit boom. In our policy experiment, five half-yearly 0.5 percentage point increases in capital requirements are likely to affect economic activity if, for example, this

[37] Over our sample period, there were notable examples when larger and more coordinated changes in capital requirements occurred in the UK (see de-Ramon et al. (2016) for detail). For example, the UK building society sector experienced a broad shift in requirements in 2002 in response to a formal review by the Financial Services Authority (FSA). In 2008, the FSA augmented its domestic individual capital guidance its so-called 4-6-8 approach, which increased both the quality and quantity of minimum requirements across a broader group of domestic institutions. Examining behaviour in response to these changes may offer insights into changes on a wider scale.

also raises the cost of financing more broadly. This could also have second-order effects on asset quality and banks' balance sheets. We have not incorporated such feedback effects in our simulation.

8. Conclusions

This paper has applied a well-established approach to examine the effects of capital requirements on bank capital ratios, lending activity and balance sheet growth. We explicitly consider the impact these requirements have on banks' targeted, long-run capital ratios and how banks alter lending supply, balance sheet size, asset portfolio risk and regulatory capital levels in attempt to meet such targets. We also examine these effects – and the driving factors – both before and after the crisis as a step toward determining whether bank behaviour changed. Understanding whether and how bank behaviour changed will be important for developing tools aimed at quantifying the effects of capital requirements on bank balance sheet adjustments in general and lending supply in particular.

Using confidential regulatory returns data from 1989 to 2013, we find a positive association between banks' capital ratios and capital requirements. Our findings suggest that banks reacted to higher requirements by raising capital ratios even when those requirements did not necessarily appear to bind. But banks did not raise capital ratios by the full amount of an increase in requirements. Rather, our results indicate that they tended to raise capital ratios by only about 30% of the increase in requirements within the first six months, and by around 90% of the change in the long-run.

We also find that to achieve these higher ratios, banks, in addition to increasing regulatory capital levels overall, reduced lending, assets and risk-weighted assets. The results, however, suggest that the effects on lending, risk-weighted asset and total asset growth were relatively modest, though we document some difference between pre- and post-crisis adjustments that are worth highlighting. Before the crisis, banks reduced loans, assets, and risk-weighted assets in addition to raising regulatory capital levels in response to an increase in capital requirements. During the crisis, however, they placed greater emphasis on reducing lending. After the crisis, this behaviour changed, with banks placing more emphasis on reducing balance sheet size and raising capital and, in particular, better-quality, tier 1 capital in response to heightened regulatory pressures.

These empirical findings can provide the basis for quantifying the effects of policies that change capital requirements. We illustrate this idea with a simple policy experiment involving the introduction of a series of higher countercyclical capital charges similar in spirit to what has been included in the final Basel III package of regulatory reforms. Simulation results confirm the modest effects on lending growth overall and more clearly delineate the possible structural change in bank behaviour from the pre- to post-crisis periods.

Although the findings depend on a partial equilibrium view of banks' balance sheet adjustment behaviour and do not take into account feedback effects from the real economy, they are useful for highlighting shortcomings with the previous capital regime and providing evidence on the intended effects of more recent efforts to address these shortcomings. In particular, our results show that banks, in an effort to alter capital ratios before the crisis, tended to focus on raising the cheapest – and least loss absorbent – capital elements to the extent permitted under regulation. That finding confirms concerns about the efficacy of capital requirements for mitigating losses and strengthening the resilience of individual banks and financial stability more broadly. Evidence on post-crisis behaviour, however, suggests that policies designed to modify such behaviour have been somewhat effective, with banks placing greater emphasis on adjusting capital ratios by raising better-quality, tier 1 capital together with less emphasis on altering balance sheet risk. Still, there remains substantial evidence that banks have a preference for first raising lower-quality capital to meet higher capital requirements, which supports ongoing policies aimed at strengthening the quality of capital.

Another implication of our results is that the relatively slow speed (c. 30% in the short-run) at which banks adjust capital ratios suggests that capital requirements may not be the most effective way to strengthen bank resilience quickly. In particular, the long-run adjustment to an increase in capital requirements of around 90% suggests that if a macroprudential policymaker targets say a 4 percentage point increase in capital ratios, it may need to recommend a higher percentage point increase to achieve that goal. This result supports the use of other regulatory tools, such as loan-to-income (LTI) flow limits for residential mortgages, to counteract emerging risks expeditiously.

Finally, while this study's results provide insights into how banks responded in the past to changes in capital requirements set at the bank level, policymakers will need to use considerable judgment in how to use them in impact assessment. This is because bank behaviour could be different under Basel III, which includes a macroprudential regime. Our results pointing to a structural change in bank behaviour after the end of the crisis support this idea and highlight just how important judgment will play in making inferences about bank balance sheet behaviour going forward.

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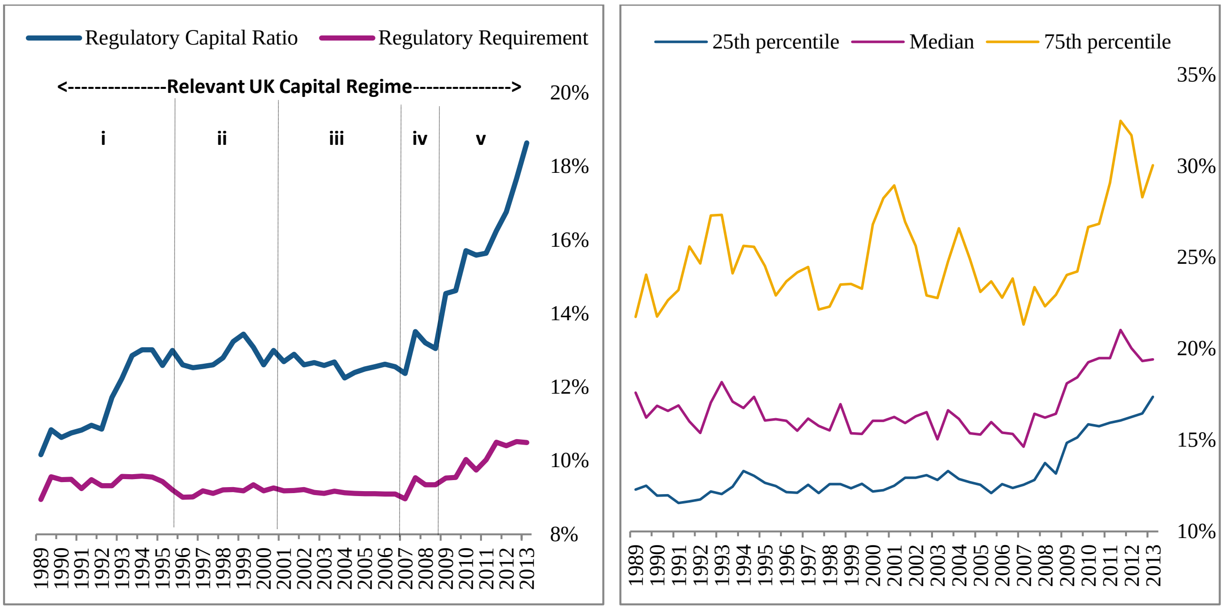
Figure 1: 1989-2013 Total regulatory requirements and total capital ratios

Panel A: Total regulatory capital requirements and total risk-based capital ratio[(a)]

Panel B: Distribution of total risk-based capital ratio

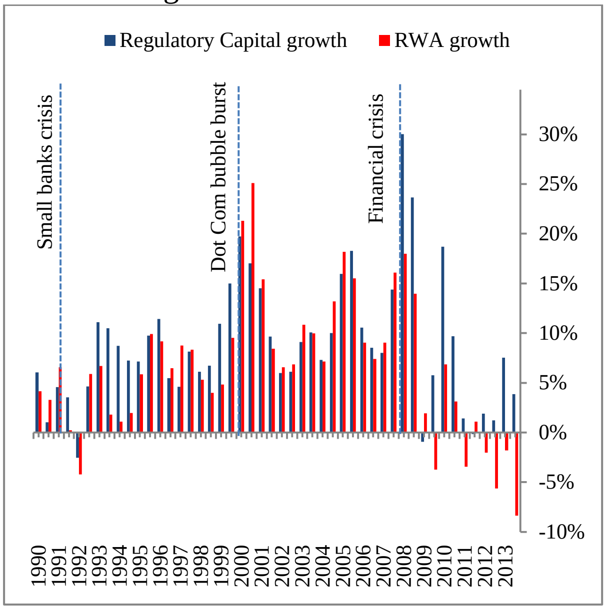


Source(s): Bank of England and authors' calculations.

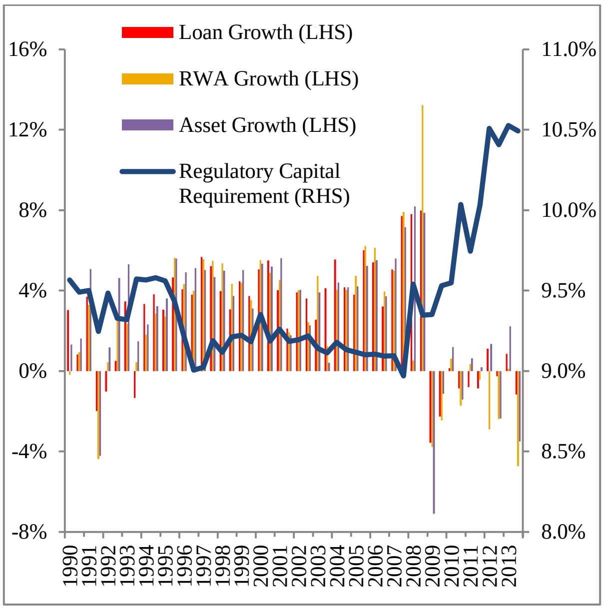
Note(s): (a) Measures based on full sample of banking groups (excluding Building Societies): 3,627 observations 179 banking groups, 49 periods of bi-annual data from December 1989 and December 2013. Relevant UK capital requirement regimes include: (i) 1990-1995 (Basel I with UK specific minimum trigger and target requirements); (ii) 1996-2001 (Basel I, Basel Market Risk Amendment (MRA), UK specific minimum trigger and requirement); (iii) 2001-2007 (Basel I, MRA, UK specific FSA Individual Capital Guidance (ICG); (iv) 2007-2009 (Basel II, MRA, FSA ICG and FSA 4/6/8 Regime); (v) 2009-2013 (Basel II, Basel 2.5, FSA 4-6-8 Regime, and UK Stress Testing). Regulatory capital ratio computed as the aggregate, across all banking groups, total regulatory capital divided by the aggregate risk-weighted assets for these firms. The regulatory capital requirement reflects the aggregate required capital divided by aggregate risk-weighted assets.

Figure 2: Regulatory capital and balance sheet growth

Panel A: Growth in total regulatory capital and risk-weighted assets[(a)]



Panel B: Growth in loans, risk-weighted assets and total and assets[(a),(b)]

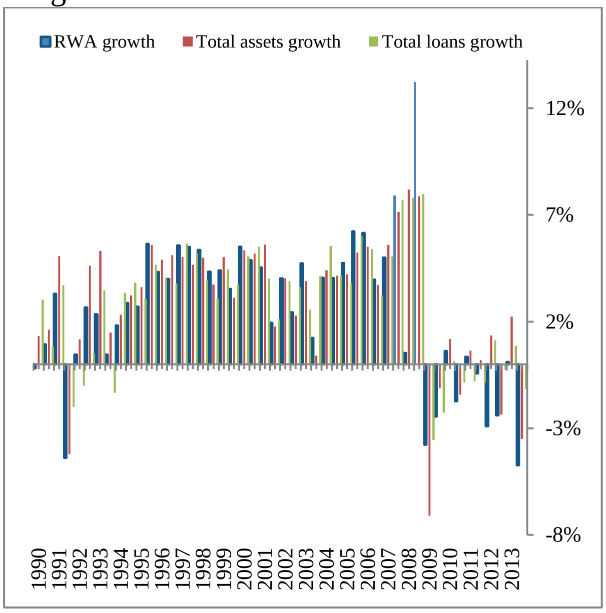


Source(s): Bank of England and authors' calculations.

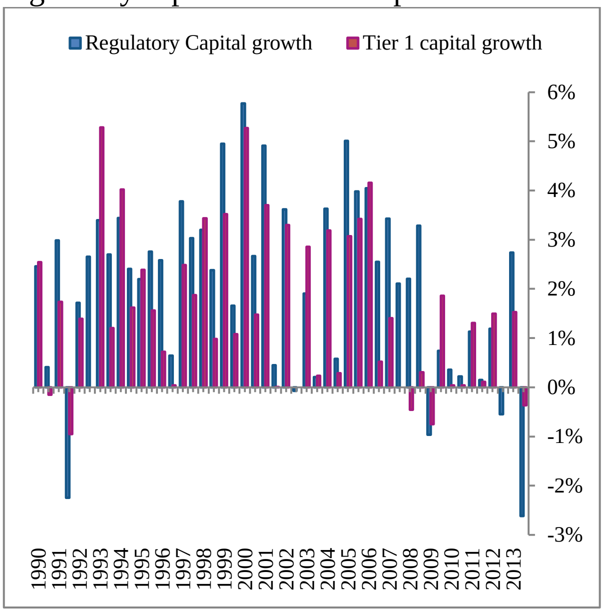
Note(s): (a) Full sample of banking groups (excluding Building Societies); 3,627 observations 179 banking groups, 49 periods of bi-annual data from December 1989 and December 2013. Percentage growth rates are semester-on-semester. Period 1989-1995 excludes risk weighted assets in the trading book. (b) The total regulatory capital requirement reflects the aggregate required capital divided by aggregate risk-weighted assets.

Figure 3: Median balance sheet growth rates

Panel A: Median growth rates in loans, risk-weighted assets and total assets[(a)]



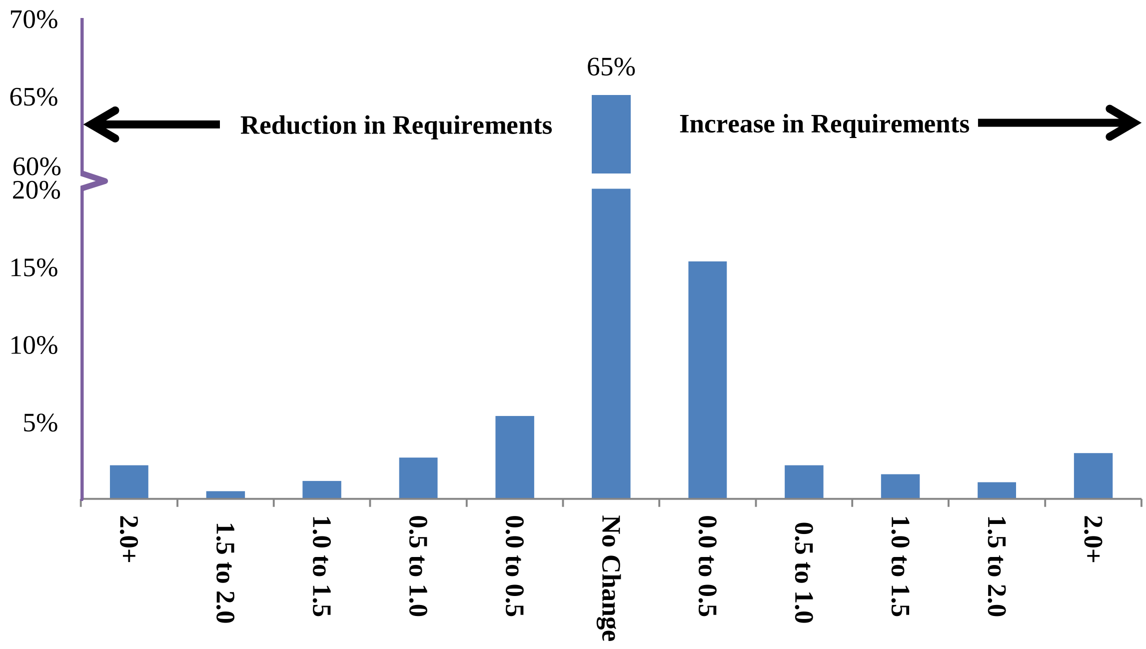
Panel B: Median growth rates in total regulatory capital and tier 1 capital[(a)]



Source(s): Bank of England and authors' calculations.

Note(s): (a) Full sample of banking groups (excluding Building Societies) 3,627 observations 179 banking groups, 49 periods of bi-annual data from December 1989 and December 2013. Percentage growth rates are half yearly rates. Period 1989-1995 excludes assets and risk weighted assets in the trading book.

Figure 4: Distribution of changes in individual capital requirements 1990 to 2013



Source: Bank of England and authors' calculations.

Figure 5: Framework for evaluating the bank capital channel

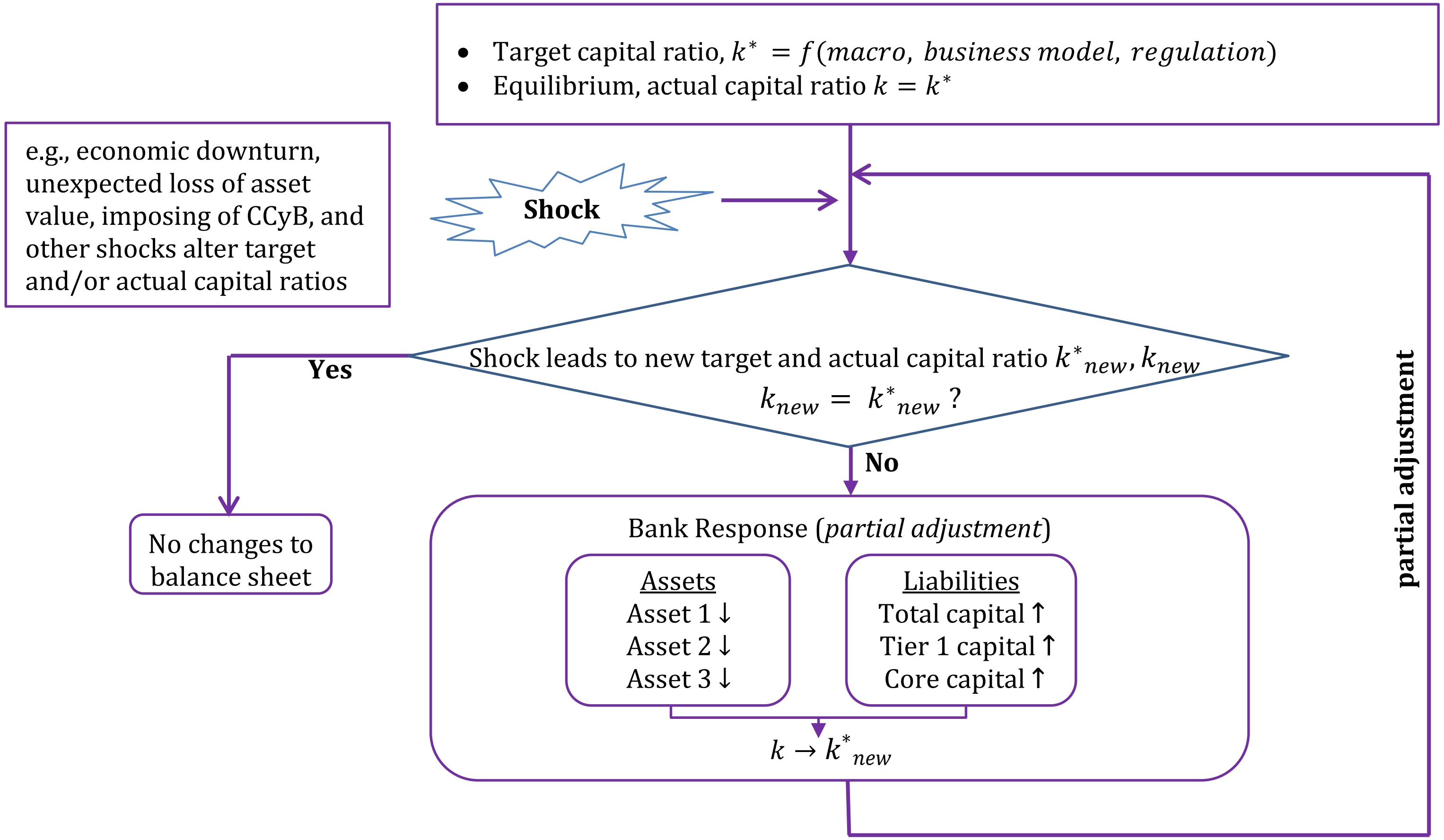
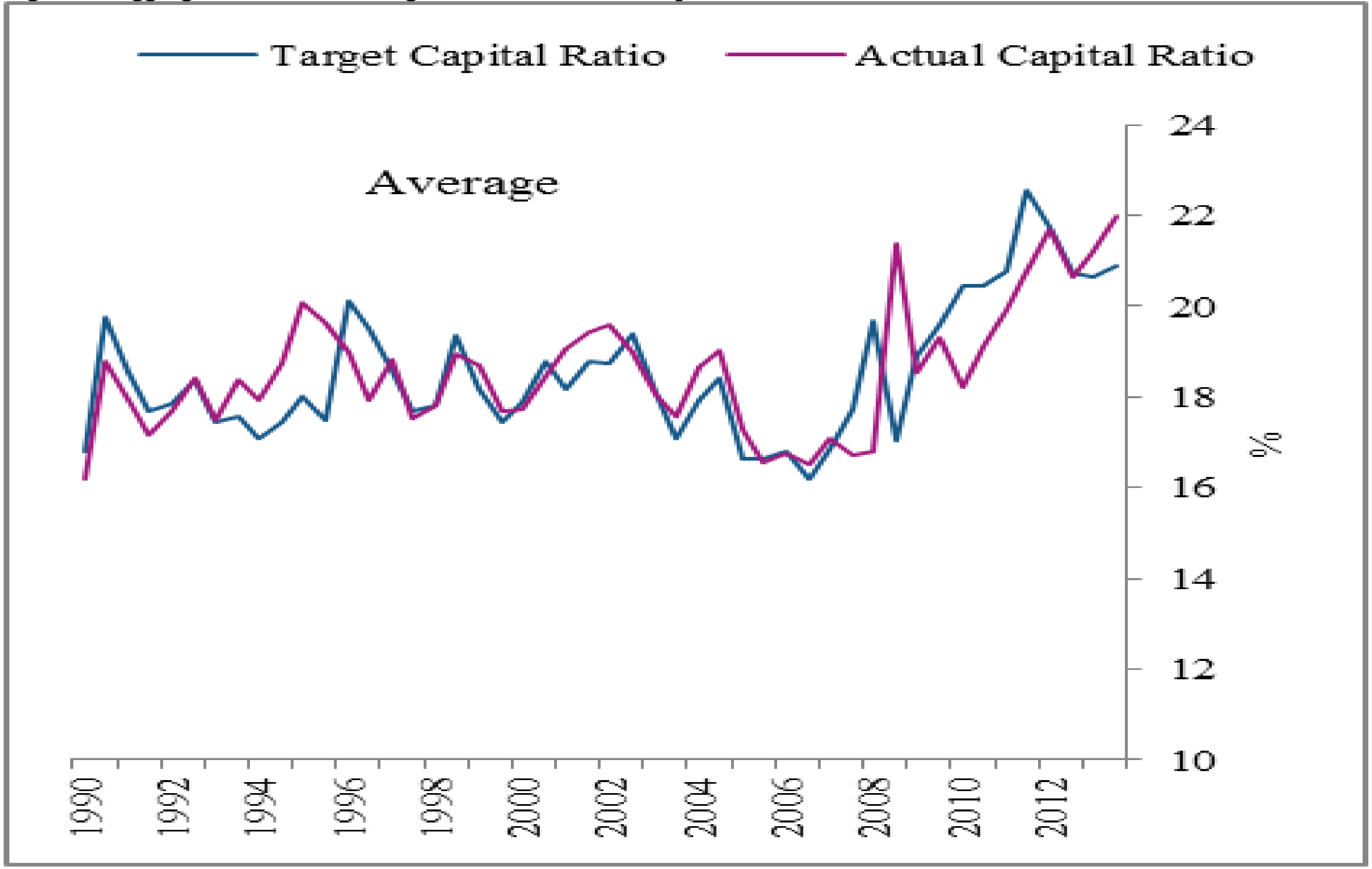


Figure 6: Aggregate Actual and Target Bank Risk-Based Capital Ratios[(a)]

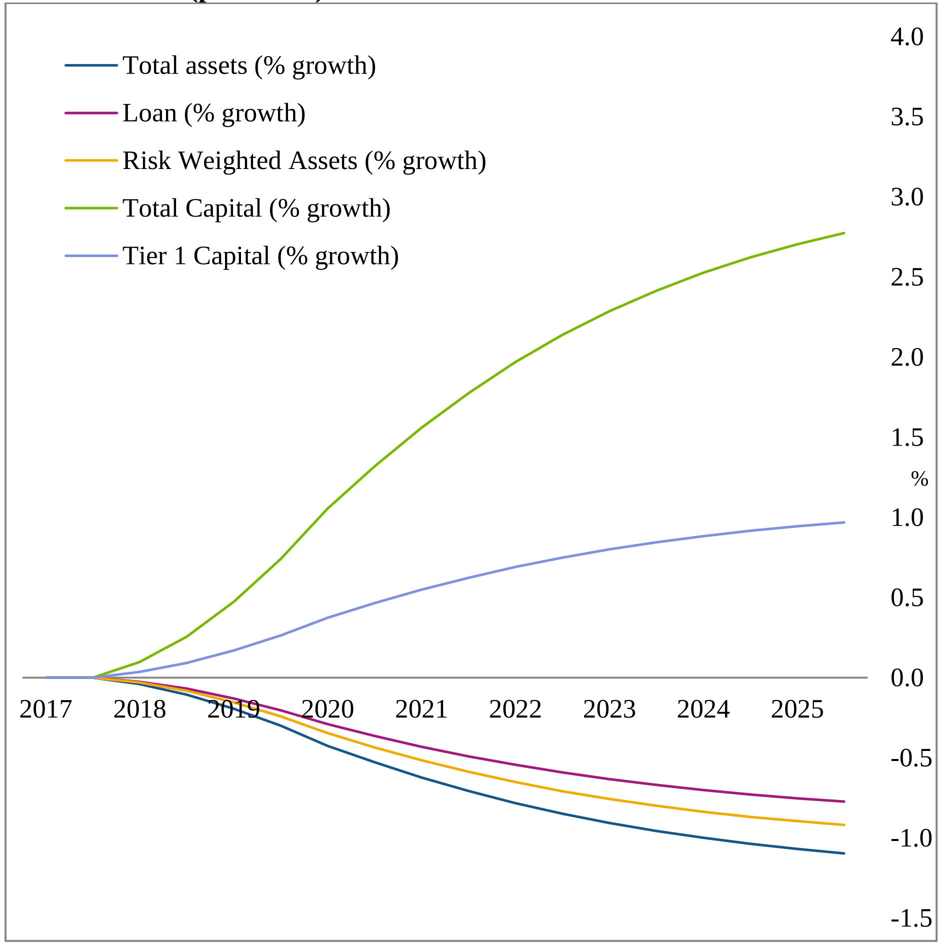


Source: Bank of England and authors' calculations.

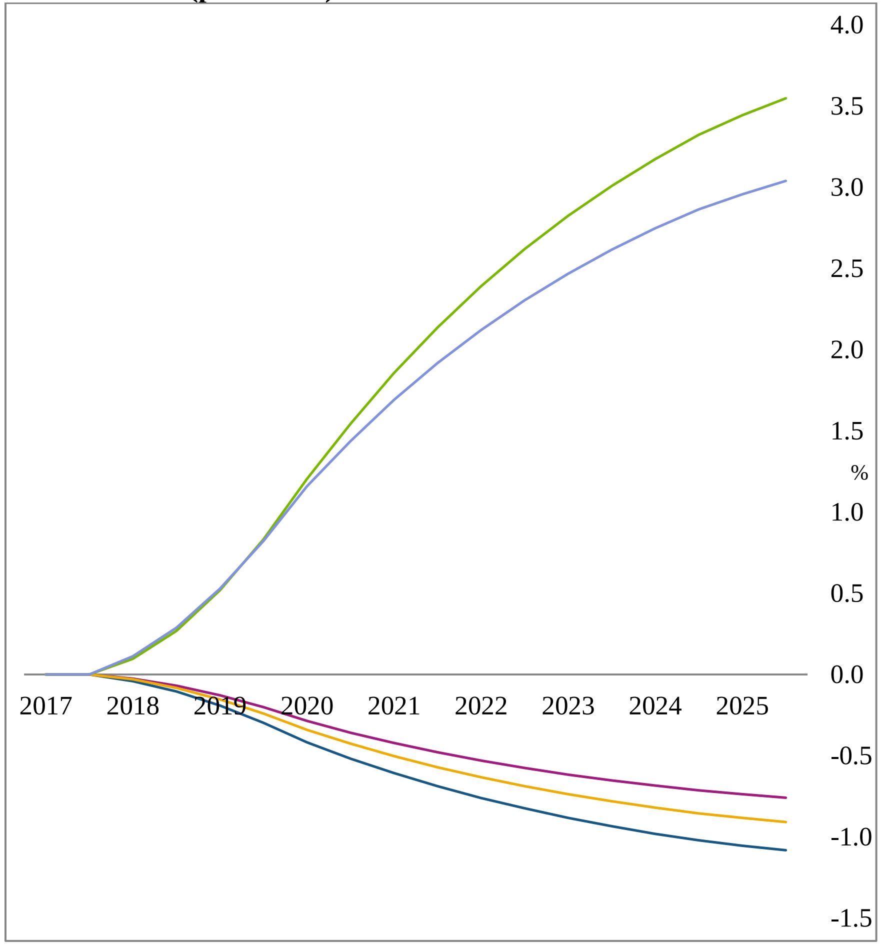
Note(s): (a) Weighted average of UK banks' actual total risk-based capital ratio and targeted total risk-based capital.

Figure 7.1: Effects of countercyclical capital requirements on balance sheet adjustments

Panel A: Impact on Loan, TA, RWA Total Capital and Tier 1 Capital Growth Rates (pre-crisis)



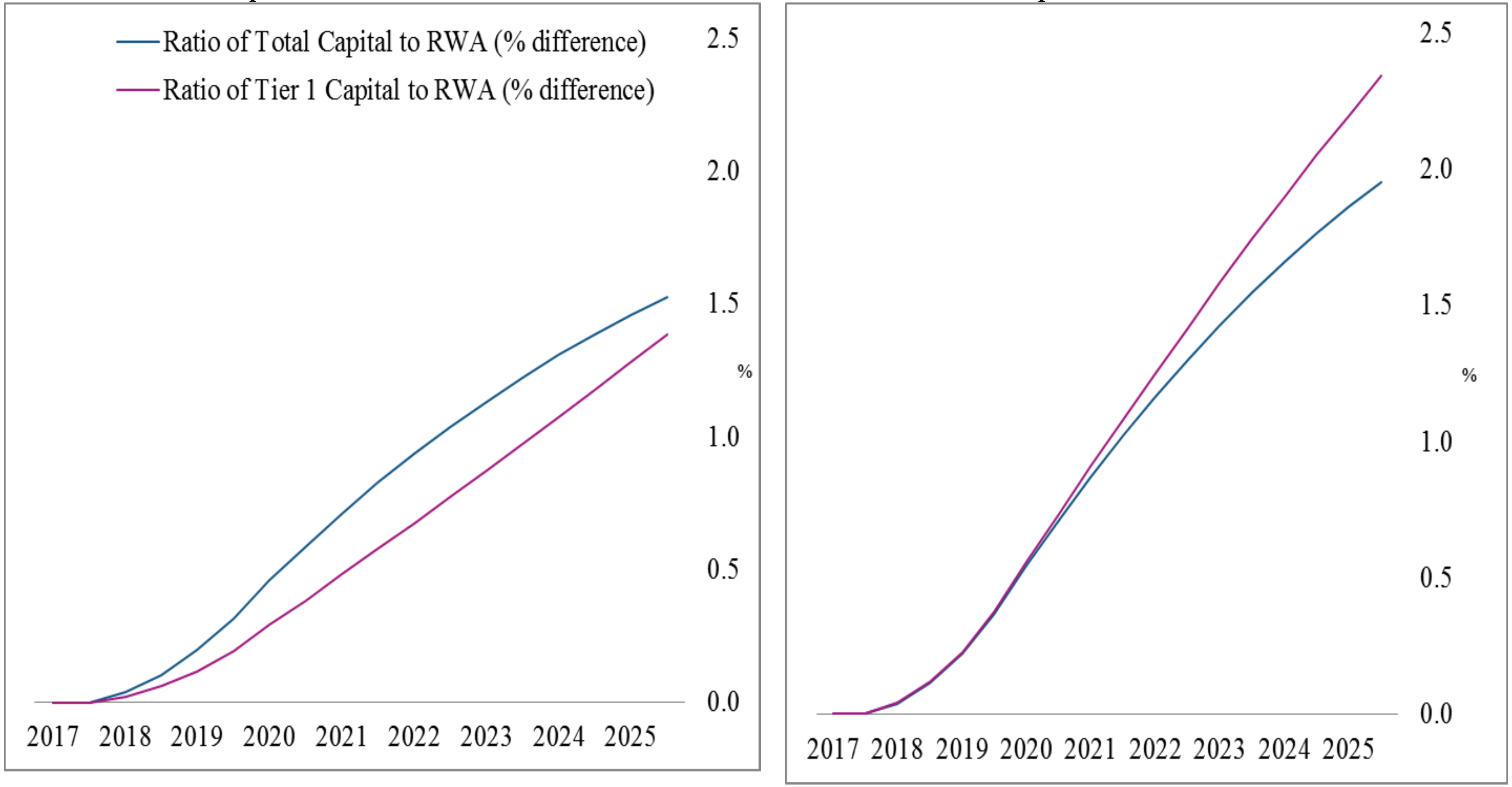
Panel B: Impact on Loan, TA, RWA Total Capital and Tier 1 Capital Growth Rates (post-crisis)



Source: Bank of England and authors' calculations.

Figure 7.2: Effects of countercyclical capital requirements on risk-based capital ratios

Panel A: Pre-crisis impact **Panel B: Post-crisis impact**



Source: Bank of England and authors' calculations.

Table 1: Summary Statistics for Bank-Level Panel Data

Variable	Number of Observations	Mean	Standard Deviation	Median	25th Percentile	75th Percentile	Minimum	Maximum
Panel A: Target Capital Model								
Total Risk Based Capital Ratio	2406	18.55	8.81	15.90	12.30	21.63	9.01	49.98
Capital Requirement	2406	11.10	2.65	10.23	9.00	12.88	8.00	20.02
Return on Equity	2263	6.46	13.73	7.37	1.90	12.96	-48.88	49.05
Trading Book Assets / Total Assets	2406	10.07	22.73	0.00	0.00	7.11	0.00	96.79
Provisions / Total Assets	2392	1.81	3.62	0.86	0.30	1.68	0.00	24.72
Tier 1 Capital / Total Capital	2406	70.66	23.51	70.41	58.74	90.39	0.22	100.00
Size (mean adjusted)	2406	1.00	2.48	0.89	-0.83	2.59	-6.94	6.83
Total Assets (£Millions)	2406	66246.22	216229.40	3820.19	663.85	21991.01	1.59	1925711.00
VIX (Monthly Average)	2406	19.61	6.62	19.15	14.95	23.63	10.96	61.18
Panel B: Balance Sheet Growth Models								
Net Charge-offs / Total Assets	2392	117.86	368.96	2.26	0.00	33.29	-6.40	2335.07
Change in Provisions	2377	-0.02	1.05	-0.01	-0.10	-0.07	-24.80	17.52
Change in UK GDP	2406	2.17	1.86	2.44	1.67	3.34	-6.00	4.71
Change in US GDP	2406	2.63	1.71	2.74	1.71	4.08	-4.15	5.13
Change in CPI	2406	0.74	0.74	0.63	0.32	1.01	-1.24	4.62
Change in Bank Rate	2406	-0.25	0.88	0.00	-0.50	0.25	-5.00	4.50
Total Loan Growth	2406	3.95	13.08	4.00	-1.70	9.71	-49.10	49.37
Total Real Estate Mortgage Growth	1904	3.65	46.04	3.38	-3.91	10.40	-444.02	761.04
Total Asset Growth	2406	3.69	11.20	3.98	-1.77	9.08	-49.58	49.76
RWA Growth	2406	3.23	10.37	3.58	-1.67	8.33	-48.97	48.26
Retail Deposit Growth	2369	2.54	37.59	3.20	-3.11	9.67	-600.18	496.35
Total Regulatory Capital Growth	2406	3.38	10.27	2.73	-1.01	7.74	-48.71	49.95
Tier 1 Capital Growth	2406	3.46	11.78	2.34	-0.50	8.12	-88.74	89.42

Source(s): Bank-level variables derived from BSD 1, 2, 3 and FSA regulatory returns and authors' calculations. The Chicago Board Options Exchange supplied the average VIX data. Changes in US and UK GDP rates computed based on data supplied by the UK Office of National Statistics and the US Bureau of Economic Analysis, respectively. UK bank rate supplied by the Bank of England.

Table 2: Determinants of Bank Target Capital Ratios (Benchmark Model)

This table reports the GMM regression estimates of specification (6) for the determinants of UK banks' target capital ratios using the full estimation sample timeframe 1989 to 2013.

$$k_{b,t} = A_b + A_1 k_{b,t-1} + B_{roe} roe_{b,t-1} + B_{cr} cr_{b,t-1} + B_{tb} tb_{b,t-1} + B_{provision} provision_{b,t-1} + B_{tier1} tier1_{b,t-1} + B_{size} size_{b,t-1} + B_{vix} vix_{t-1} + \varepsilon_{b,t} .$$

Variables	Target (short-run)	Target (long-run)	Target (short-run)	Target (long-run)
Capital Ratio (k_b)	0.68***		0.67***	
	(0.09)		(0.09)	
Return on Equity (roe)	-0.02***		-0.01**	
	(0.01)		(0.01)	
Capital Requirement (cr)	0.26***		0.29***	
	(0.08)		(0.09)	
Trading Book (tb)	0.02***		0.02***	
	(0.01)		(0.01)	
Loan Loss Provision (provision)	0.07		0.07	
	(0.06)		(0.06)	
Tier 1 Share (tier1)	0.03***		0.04***	
	(0.01)		(0.01)	
Asset Size (size)	-0.33***		-0.33***	
	(0.11)		(0.12)	
Market Volatility (vix)	0.03**			
	(0.01)			
Adjustment Speed per Period (1-A_1)		0.32***		0.33***
		(0.09)		(0.09)
Tier 1 Share (tier1)		0.11***		0.11***
		(0.02)		(0.02)
Trading Book (tb)		0.06***		0.06***
		(0.01)		(0.01)
Capital Requirement (cr)		0.80***		0.86***
		(0.15)		(0.16)
Loan Loss Provision (provision)		0.23		0.20
		(0.15)		(0.16)
Asset Size (size)		-1.02***		-1.00***
		(0.22)		(0.22)
Return on Equity (roe)		-0.05**		-0.04**
		(0.02)		(0.02)
Market Volatility (vix)		0.08**		
		(0.04)		
Constant	0.11			
	(0.74)			
Time period effects	No	No	Yes	Yes
Observations	2,179	2,179	2,179	2,179
Number of banks	114		114	
Number of instruments	12		58	
AR1	1.16E-07		1.58E-07	
AR2	0.161		0.133	
Hansen	0.570		0.602	

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10

Table 3: Determinants of Bank Target Capital Ratios (Analysis of structural breaks)

This table reports the long-run coefficients from GMM regression estimates of specification (6) for the determinants of UK banks' target capital ratios using the full estimation sample timeframe 1989 to 2013 and data spanning two (three) distinct periods of time: pre-crisis (1989 to 2007) and after-crisis (2010 to 2013).

$$k_{b,t} = A_b + A_1 k_{b,t-1} + B_{roe} roe_{b,t-1} + B_{cr} cr_{b,t-1} + B_{tb} tb_{b,t-1} + B_{provision} provision_{b,t-1} + B_{tier1} tier1_{b,t-1} + B_{size} size_{b,t-1} + \lambda_t + \varepsilon_{b,t}$$

Long-run Coefficients	**1989-2013[(a)]**	**1989-2007[(a)]**	**2010-2013[(a)]**
Adjust ($1\text{-}A_1$)	0.33***	0.32***	0.36***
	(0.09)	(0.09)	(0.14)
Tier1 proportion (tier1)	0.11***	0.10***	0.07
	(0.02)	(0.03)	(0.06)
Trading book ratio (tb)	0.06***	0.05***	0.06
	(0.01)	(0.01)	(0.04)
Capital requirements (cr)	0.86***	0.98***	0.86***
	(0.16)	(0.17)	(0.29)
Loan Provisions (provision)	0.20	0.37***	-0.24*
	(0.16)	(0.10)	(0.14)
Bank Size (size)	-1.00***	-0.96***	-0.52
	(0.22)	(0.23)	(0.38)
Return on Equity (roe)	-0.04**	-0.02	-0.05
	(0.02)	(0.02)	(0.04)
Observations	2,179	1,810	275
Number of banks	114	101	43
Number of instruments	12	46	19
AR1	1.58E-07	9.10E-07	1.73E-03
AR2	0.133	0.104	0.736
Hansen	0.602	0.642	0.714
Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10			
Source(s): Bank of England. Note(s): (a) estimated by GMM using data from selected timeframes and using bank and time period effects.			

Table 4: Determinants of Bank Target Capital Ratios (Pre- versus Post-2007)

This table reports the GMM regression estimates of equation (9) for the determinants of UK banks' target capital ratios using the full estimation sample timeframe 1989 to 2013, which accounts for potential structural changes in behaviour after 2007.

$$k_{b,t} = A_b + (A_1 + A_2 D_{2007})k_{b,t-1} + (B_{roe} + B'_{roe} D_{2007})roe_{b,t-1} + (B_{cr} + B'_{cr} D_{2007})cr_{b,t-1}$$
$$+ (B_{tb} + B'_{tb} D_{2007})tb_{b,t-1} + (B_{provision} + B'_{provision} D_{2007})\,provision_{b,t-1}$$
$$+ (B_{tier1} + B'_{tier1} D_{2007})tier1_{b,t-1} + (B_{size} + B'_{size} D_{2007})size_{b,t-1} + D_{2007} + \lambda_t + \varepsilon_{b,t}.$$

Variables	Target (short-run)	Target (long-run pre-2007)	Target (long-run post-2007)
Capital Ratio (k_b)	0.69***		
	(0.11)		
Capital Ratio_Post_2007 (k_b*D_{2007})	0.03		
	(0.43)		
Return on equity (roe)	-0.00		
	(0.01)		
Return on equity_Post_2007 (roe* D_{2007})	-0.01		
	(0.01)		
Capital Requirement (cr)	0.34***		
	(0.12)		
Capital Requirement_Post_2007 (cr* D_{2007})	-0.14		
	(0.38)		
Trading Book Ratio (tb)	0.01*		
	(0.01)		
Trading Book Ratio_Post_2007 (tb* D_{2007})	0.01		
	(0.01)		
Loan Provisions (provisions)	0.11*		
	(0.06)		
Loan Provisions_Post_2007 (provision* D_{2007})	-0.16*		
	(0.09)		
Tier 1 Share (tier1)	0.03*		
	(0.01)		
Tier 1 Share_Post_2007 (tier1* D_{2007})	-0.01		
	(0.05)		
Bank Size (size)	-0.32**		
	(0.16)		
Bank Size_Post_2007 (size* D_{2007})	0.13		
	(0.26)		
D_{2007}	2.49		
	(2.54)		
Adjustment Speed:			
Pre-2007 (1-A_1); Post-2007 (1- A_1- A_2)		0.31***	0.28
		(0.11)	(0.43)
Tier 1 Share (tier1)		0.09***	0.05
		(0.03)	(0.08)
Trading Book Ratio (tb)		0.04**	0.07
		(0.02)	(0.07)
Capital Requirement (cr)		1.09***	0.71*
		(0.19)	(0.38)
Loan Provisions (provision)		0.36***	-0.19
		(0.12)	(0.18)
Bank Size (size)		-1.03***	-0.67
		(0.30)	(0.65)
Return on Equity (roe)		-0.01	-0.06
		(0.02)	(0.12)
Time-period effects	Yes	Yes	Yes
Obervations	2,179	2,179	2,179
Number of banks	114		
Number of instruments	68		Joint test chi(7)
AR1	2.78E-07		18.64***
AR2	0.136		
Hansen	0.750		

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Determinants of Bank Target Capital Ratios (Crisis Controls)

This table reports the GMM regression estimates of equation (10) for the determinants of UK banks' target capital ratios using the full estimation sample timeframe 1989 to 2013, which accounts for potential structural changes in behaviour during and after the crisis period, defined as spanning from the second half of 2007 to the end of 2009 (2007H2 to 2009H2).

$$k_{b,t} = A_b + (A_1 + A_2 I_C + A_3 I_{PC})k_{b,t-1} + (B_{roe} + B'_{roe} I_C + B''_{roe} I_{PC})roe_{b,t-1} + (B_{cr} + B'_{cr} I_C + B''_{cr} I_{PC})cr_{b,t-1}$$
$$+ (B_{tb} + B'_{tb} I_C + B''_{tb} I_{PC})tb_{b,t-1} + (B_{provision} + B'_{provision} I_C + B''_{provision} I_{PC})\, provision_{b,t-1}$$
$$+ (B_{tier1} + B'_{tier1} I_C + B''_{tier1} I_{PC})tier1_{b,t-1} + (B_{size} + B'_{size} I_C + B''_{size} I_{PC})size_{b,t-1}$$
$$+ I_C + I_{PC} + \lambda_t + \varepsilon_{b,t}\,.$$

Variables	**Target (short-run)**	**Target (long-run pre-crisis)**	**Target (long-run during crisis)**	**Target (long-run after crisis)**
Capital Ratio (k_b)	0.63***			
	(0.13)			
Capital Ratio_crisis (cr*I_C)	-0.37**			
	(0.16)			
Capital Ratio_aftercrisis (cr*I_{PC})	0.10			
	(0.15)			
Return on Equity (roe)	-0.01			
	(0.01)			
Return on Equity_crisis (roe*I_C)	0.01			
	(0.02)			
Return on Equity_aftercrisis (roe*I_{PC})	-0.01			
	(0.02)			
Capital Requirements (cr)	0.40***			
	(0.13)			
Capital Requirements_crisis (cr*I_C)	-0.33			
	(0.26)			
Capital Requirements_aftercrisis (cr*I_{PC})	-0.14			
	(0.22)			
Trading Book (tb)	0.02**			
	(0.01)			
Trading Book_crisis (tb*I_C)	0.01			
	(0.02)			
Trading Book_aftercrisis (tb*I_{PC})	-0.01			
	(0.01)			
Loan Provisions (provision)	0.15**			
	(0.06)			
Loan Provisions_crisis (provisions*I_C)	-0.11			
	(0.13)			
Loan Provisions_aftercrisis (provisions*I_{PC})	-0.17**			
	(0.08)			
Tier 1 Share (tier1)	0.04**			
	(0.01)			
Tier 1 Share_crisis (tier1*I_C)	-0.01			
	(0.03)			
Tier 1 Share_aftercrisis (tier1*I_{PC})	0.21			
	(0.17)			
Bank Size (size)	-0.32**			
	(0.14)			
Bank Size_crisis (size*I_C)	-0.50			
	(0.33)			

Bank Size_aftercrisis (size*I_{PC})	0.21			
	(0.17)			
I_C (During Crisis Dummy)	11.91**			
	(5.00)			
I_{PC} (After Crisis Dummy)	2.53			
	(1.82)			
Adjustment Speeds:				
Pre-Crisis (1-A_1)				
During Crisis (1-A_1-A_2*I_C)				
After Crisis (1-A_1-A_3*I_{PC})		0.37***	0.74***	0.28***
		(0.13)	(0.19)	(0.10)
Tier 1 Share (tier1)		0.10***	0.04	0.02
		(0.03)	(0.04)	(0.07)
Trading Book Ratio (tb)		0.05***	0.05**	0.03
		(0.01)	(0.02)	(0.04)
Capital Requirement (cr)		1.06***	0.08	0.92**
		(0.17)	(0.28)	(0.42)
Loan Provisions (provision)		0.40***	0.06	-0.08
		(0.11)	(0.17)	(0.20)
Bank Size (size)		-0.85***	-1.11***	-0.39
		(0.21)	(0.32)	(0.37)
Return on Equity (roe)		-0.02	0.00	-0.07
		(0.02)	(0.03)	(0.07)
Period effects	Yes	Yes	Yes	Yes
Observations	2,179	2,179	2,179	2,170
Number of banks	114			
Number of instruments	78		Joint test chi(8)	Joint test chi(8)
AR1	5.28E-06		21.77***	11.72
AR2	0.106			
Hansen	0.504			
Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1				

Table 6: Analysis of persistence component of growth regressions

This table reports the GMM regression estimates of balance sheet growth specification (8) using the full estimation sample timeframe 1989 to 2013 and the pre-crisis period 1989 to 2007. The coefficient estimates reported in the table are those on the lagged dependent variable in the specifications below.

$$\Delta lnBS_{j,b,t} = \gamma_b + \alpha_j \Delta lnBS_{j,b,t-1} + \beta_Z Z_{b,t-1} + \delta_{PROV}\Delta PROVISIONS_{b,t} + \delta_{CO}CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}$$

$$\Delta lnBS_{j,b,t} = \gamma_b + \sum_{l=1}^{2} \alpha_{l,j}\, \Delta lnBS_{j,b,t-l} + \beta_Z Z_{b,t-1} + \delta_{PROV}\Delta PROVISIONS_{b,t} + \delta_{CO}CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}$$

Data Period (number of lags)	Lag	Loans	Total Assets	RWA	Total Capital	Tier 1 Capital
1989-2007 (2 lags)	t-1	0.02	-0.13*	-0.01	-0.06*	-0.11*
	t-2	0.00	0.00	0.00	-0.01**	-0.01
1989-2007 (1 lag)	t-1	0.02	-0.15*	-0.01	-0.08**	-0.11*
1989-2013 (2 lags)	t-1	-0.02	-0.14**	-0.02	-0.06	-0.12**
	t-2	0.00	0.00	-0.00	-0.01**	-0.00
1989-2013 (1 lag)	t-1	-0.03	-0.16**	-0.02	-0.08*	-0.10*

Significance level *** p<0.01, ** p<0.05,* p<0.10.

Table 7: Long-run coefficients from preferred models (full sample period results)

This table reports long-run coefficient estimates from the extended balance sheet growth models modified to test for change during and after the crisis using specification (8).

$$\Delta lnBS_{j,b,t} = \gamma_b + \alpha_j \Delta lnBS_{j,b,t-1} + \beta_Z Z_{b,t-1} + \delta_{PROV} \Delta PROVISIONS_{b,t} + \delta_{CO} CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}.$$

	Growth in balance sheet item j:				
Variable	**Loans[(a)]**	**Assets[(b)]**	**RWA [(a)]**	**Total Capital[(b)]**	**Tier 1 Capital[(b)]**
Z_b	0.04***	0.06***	0.05***	-0.17***	-0.08***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)
ΔProvisions$_b$	-1.12**	-3.37***	-1.74***	-0.11	-1..02
	(0.45)	(0.73)	(0.34)	(0.77)	(0.67)
Chargeoff$_b$	-0.80**	-0.39***	-0.68***	-0.22	-0.40*
	(0.33)	(0.15)	(0.24)	(0.21)	(0.23)
Overall lagged values effects					
Constant	-3.86	-2.73	-0.73	-1.63	2.62
	(5.09)	(2.14)	(3.82)	(2.24)	(2.36)
Observations		1917		1917	1976
Number of groups		107		107	107
Number of instruments		56		56	56
AR(1) p-value		0.0000		0.0000	0.0000
AR(2) p-value		0.1050		0.1290	0.0727
Hansen test p-value		0.0956		0.2060	0.5960
Observations	1917		1917		
Number of groups	107		107		
R-squared	0.06		0.14		
R-squared (within)	0.0554		0.1350		
R-squared (overall)	0.0483		0.1120		
R-squared (between)	0.0272		0.0213		

Standard errors in parentheses; *** p<0.01, ** p<0.05,* p<0.10.

Note(s): (a) estimated using fixed effects with time and firm effects; (b) estimated using GMM with time effects; firm and period fixed effects not reported.

Table 8: Analysis of structural change in balance sheet growth relationships

This table reports Wald test statistics of the hypotheses that the interaction terms are jointly equal to zero in the extended benchmark balance sheet growth models set out in equations (11) and (12). The most relevant estimator is highlighted in bold typeface. Significant test statistics indicate that the null hypothesis that all interaction terms are jointly equal to zero can be rejected, consistent with there being structural change.

Pre- versus Post-2007 Specification:

$$\Delta lnBS_{j,b,t} = \gamma_b + D_{2007} + (\alpha_j + \alpha_j' D_{2007})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta_z' D_{2007})Z_{b,t-1}$$
$$+ (\delta_{PROV} + \delta_{PROV}' D_{2007})\Delta PROVISIONS_{b,t} + (\delta_{CO} + \delta_{CO}' D_{2007})CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}.$$

Pre- versus During versus Post-Crisis Specification:

$$\Delta lnBS_{j,b,t} = \gamma_b + I_C + I_{PC} + (\alpha_j + \alpha_j' I_C + \alpha_j'' I_{PC})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta_z' I_C + \beta_z'' I_{PC})Z_{b,t-1}$$
$$+ (\delta_{PROV} + \delta_{PROV}' I_C + \delta_{PROV}'' I_{PC})\Delta PROVISIONS_{b,t} + (\delta_{CO} + \delta_{CO}' I_C + \delta_{CO}'' I_{PC})CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}.$$

	Growth of balance sheet item j:				
Panel A: Overall test on all interactions	**Loans**	**Assets**	**RWA**	**Total Capital**	**Tier 1 Capital**
Post 2007 by GMM	2.11	**15.41****	12.74**	**40.39*****	**4.53**
Post 2007 by Fixed Effects	**1.49**	3.46***	**2.67****	2.49**	2.35*
During crisis by GMM	25.12***	**18.33*****	90.43***	**84.50*****	**61.21*****
During crisis by Fixed Effects	**13.39*****	13.94***	**20.81*****	48.74***	30.23***
After crisis by GMM	6.28	**9.72**	9.67	**24.14*****	**14.93****
After crisis by Fixed Effects	**1.17**	3.33**	**2.94****	17.95***	5.49***

Source(s): Bank of England and authors' calculations.

Note(s): The statistics show the value and significance level of Wald tests of composite linear hypotheses; significance level of the test *** p<0.01, ** p<0.05,* p<0.10.

Table 9.1: Short-run coefficients from preferred models (during and after analysis)

This table reports short-run coefficient estimates from the extended balance sheet growth models modified to test for change during and after the crisis using specification (12). Interaction terms reported in the table represent the marginal effects associated with the variables in the crisis and after-crisis periods (relative to the pre-crisis effects).

Pre- versus During versus Post-Crisis Specification:

$$\Delta lnBS_{j,b,t} = \gamma_b + I_C + I_{PC} + (\alpha_j + \alpha_j' I_C + \alpha_j'' I_{PC})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta_z' I_C + \beta_z'' I_{PC})Z_{b,t-1}$$
$$+ (\delta_{PROV} + \delta_{PROV}' I_C + \delta_{PROV}'' I_{PC})\Delta PROVISIONS_{b,t} + (\delta_{CO} + \delta_{CO}' I_C + \delta_{CO}'' I_{PC})CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}.$$

	Growth in balance sheet item j:				
Variable	**Loans[(a)]**	**Assets[(b)]**	**RWA [(a)]**	**Total Capital[(b)]**	**Tier 1 Capital[(b)]**
Z_b	0.05***	0.08***	0.06***	-0.19***	-0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Z_b *DuringCrisis	0.12*	-0.08	0.07	0.09	0.10
	(0.06)	(0.08)	(0.06)	(0.06)	(0.07)
Z_b*AfterCrisis	-0.09	0.03	-0.01	-0.02	-0.15*
	(0.10)	(0.05)	(0.05)	(0.06)	(0.09)
ΔProvisions$_b$	-1.32**	-2.59***	-2.25***	-0.87	-0.94*
	(0.53)	(0.66)	(0.46)	(0.54)	(0.56)
ΔProvisions$_b$*DuringCrisis	5.14	5.80	11.36***	6.07**	11.54***
	(3.17)	(6.94)	(2.83)	(2.47)	(2.97)
ΔProvisions$_b$ *AfterCrisis	-1.00	-2.26	1.11	-0.07	-1.61
	(1.90)	(1.93)	(1.66)	(1.40)	(2.86)
Chargeoffs$_b$	-0.78*	-0.49*	-0.72*	0.28	-0.17
	(0.43)	(0.27)	(0.40)	(0.22)	(0.27)
Chargeoffs$_b$*DuringCrisis	-0.75	-0.02	0.19	-2.07**	0.03
	(0.96)	(1.58)	(0.63)	(0.90)	(0.84)
Chargeoffs$_b$ *AfterCrisis	0.23	0.03	-0.27*	-1.35***	-0.96***
	(0.25)	(0.31)	(0.15)	(0.32)	(0.34)
During Crisis Indicator (I_C)	-11.12*	-1.75	-10.47	2.48	5.98*
	(6.09)	(2.90)	(7.74)	(1.84)	(3.33)
After Crisis Indicator (I_{PC})	-6.50*	-2.61	-7.70***	-2.48	3.27
	(3.43)	(1.84)	(2.41)	(1.87)	(2.98)
Observations		1916		1916	1916
Number of groups		107		107	107
Number of instruments		84		84	84
AR(1) p-value		0.0000		0.0000	0.0000
AR(2) p-value		0.0567		0.0647	0.2760
Hansen test p-value		0.2040		0.9890	0.3660
During crisis Prob > chi2(6) =		0.0055		0.0000	0.0000
After crisis Prob > chi2 (6) =		0.1368		0.0005	0.0208
Observations	1917		1917		
Number of groups	107		107		
R-squared	0.06		0.16		
R-squared (within)	0.0643		0.1570		
R-squared (overall)	0.0555		0.1270		
R-squared (between)	0.0169		0.0181		
During crisis Prob > F(4, 106) =	0.0000		0.0000		
After crisis Prob > F(4, 106) =	0.1409		0.0237		

Standard errors in parentheses; *** p<0.01, ** p<0.05,* p<0.10

Note(s): (a) estimated using fixed effects with time and firm effects; (b) estimated using GMM with time effects.

Table 9.2: Long-run coefficients from preferred models (during and after analysis)

This table reports long-run coefficient estimates from the extended balance sheet growth models modified to test for change during and after the crisis using specification (12). The values reported in the table represent the actual coefficients associated with the variables in the pre-crisis, crisis and after-crisis periods (i.e., not the marginal effects).

Pre- versus During versus Post-Crisis Specification:

$$\Delta lnBS_{j,b,t} = \gamma_b + I_C + I_{PC} + (\alpha_j + \alpha_j' I_C + \alpha_j'' I_{PC})\Delta lnBS_{j,b,t-1} + (\beta_Z + \beta_z' I_C + \beta_z'' I_{PC})Z_{b,t-1}$$

$$+ (\delta_{PROV} + \delta_{PROV}' I_C + \delta_{PROV}'' I_{PC})\Delta PROVISIONS_{b,t} + (\delta_{CO} + \delta_{CO}' I_C + \delta_{CO}'' I_{PC})CHARGEOFF_{b,t} + \lambda_t + \varepsilon_{b,t}.$$

	Growth in balance sheet item j:				
Variable	**Loans[(a)]**	**Assets[(b)]**	**RWA [(a)]**	**Total Capital[(b)]**	**Tier 1 Capital[(b)]**
Z_b	0.05***	0.07***	0.06***	-0.17***	-0.06***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Z_b *DuringCrisis	0.17***	-0.00	0.12**	-0.10	0.02
	(0.06)	(0.07)	(0.05)	(0.06)	(0.05)
Z_b*AfterCrisis	-0.04	0.10**	0.04	-0.26***	-0.21**
	(0.09)	(0.04)	(0.05)	(0.08)	(0.09)
ΔProvisions$_b$	-1.32**	-2.32***	-2.25***	-0.81	-0.84*
	(0.53)	(0.61)	(0.46)	(0.54)	(0.50)
ΔProvisions$_b$*DuringCrisis	3.82	3.28	9.10***	5.18**	8.27***
	(3.00)	(6.89)	(2.74)	(2.38)	(2.89)
ΔProvisions$_b$ *AfterCrisis	-2.32	-4.77***	-1.14	-1.14	-2.47
	(1.91)	(1.79)	(1.64)	(1.47)	(3.07)
Chargeoffs$_b$	-0.78*	-0.44*	-0.72*	0.26	-0.15
	(0.43)	(0.25)	(0.40)	(0.20)	(0.24)
Chargeoffs$_b$*DuringCrisis	-1.53	-0.51	-0.53	-1.78*	-0.11
	(0.99)	(1.74)	(0.69)	(0.95)	(0.65)
Chargeoffs$_b$ *AfterCrisis	-0.55	-0.45	-0.45	-1.31***	-1.10***
	(0.45)	(0.30)	(0.35)	(0.39)	(0.28)
During Crisis Indicator (I_C)	-11.12*	-1.75	-10.47	2.48	5.98*
	(6.09)	(2.90)	(7.74)	(1.84)	(3.33)
After Crisis Indicator (I_{PC})	-6.50*	-2.61	-7.70***	-2.48	3.27
	(3.43)	(1.84)	(2.41)	(1.87)	(2.98)
Overall lagged values effects		-0.11		-0.07**	-0.12*
		(0.08)		(0.04)	(0.07)
Overall lagged values effects*DuringCrisis		0.02		-0.00	-0.28
		(0.20)		(0.21)	(0.26)
Overall lagged values effects*AfterCrisis		-0.02		0.18*	-0.03
		(0.13)		(0.09)	(0.14)
Observations		1916		1916	1916
Number of groups		107		107	107
Number of instruments		84		84	84
AR(1) p-value		0.0000		7.83e-11	0.0000
AR(2) p-value		0.0567		0.0647	0.276
Hansen test p-value		0.204		0.989	0.366
During crisis Prob > chi2(6) =		0.0055		0.0000	0.0000
After crisis Prob > chi2 (6) =		0.1368		0.0005	0.0208
Observations	1917		1917		
Number of groups	107		107		
R-squared	0.06		0.16		
R-squared (within)	0.0643		0.157		
R-squared (overall)	0.0555		0.127		
R-squared (between)	0.0169		0.0181		
During crisis Prob > F(4, 106) =	0.0000		0.0000		
After crisis Prob > F(4, 106) =	0.1409		0.0237		

Standard errors in parentheses; *** p<0.01, ** p<0.05,* p<0.10

Note(s): (a) estimated using fixed effects with time and firm effects; (b) estimated using GMM with time effects.

Table 10: Robustness analysis

This table shows the results of tests to evaluate the possibility that the effects of bank capitalization on balance sheet growth (i) depend on the economic cycle, (ii) depend on the systemic importance (size) of the bank and (iii) are non-linear. The table summarizes the significance of the marginal effects of bank capitalization (bank capital requirements) across the economic cycle and for systemic banks.

	Loans	Assets	RWA	Total Capital	Tier 1 Capital
1. UK GDP interaction	**-**	**n/s**	**-**	**n/s**	**n/s**
2. US GDP interaction	**n/s**	**n/s**	**n/s**	**n/s**	**n/s**
3. Systemic banks	**n/s**	**n/s**	**n/s**	**n/s**	**n/s**
4. Quadratic Z (non-linear)	**n/s**	**n/s**	**-**	**++**	**n/s**

Note(s): n/s = non-significant;
Negative parameters: "- "10% significance; "--" 5% significance; "---" 1% significance.
Positive parameters: "+" 10% significance; "++" 5% significance; "+++" 1% significance.

Table 11: Pro-forma effects of countercyclical capital requirements

This table reports the long-run impacts and period-average effect on balance sheet and capital growth of five equal increases in capital requirements of 0.50% introduced half-yearly for over five successive semi-annual periods. Panel A figures show the amount the long-run changes in response to higher capital requirements based on response parameters estimated for the pre-crisis period (1989-2007) and response parameters estimated for the post-crisis period (2010-2013) compared to the baseline case where the requirements are not introduced. Panel A also shows the distribution of these changes. Panel B shows the distribution among different firms of the period-average annual growth change with respect to the baseline case.

	Loans		**Total Assets**		**RWA**		**Total Capital**		**Tier 1 Capital**	
Panel A: Long term change with respect to baseline	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**
Mean	-0.8	-0.9	-1.2	-1.2	-1.0	-1.0	3.0	4.1	1.0	3.5
25th Percentile	-1.0	-1.0	-1.4	-1.4	-1.2	-1.2	2.5	3.5	0.9	2.9
50th Percentile	-0.8	-0.9	-1.2	-1.2	-1.0	-1.0	3.0	4.1	1.0	3.5
75th Percentile	-0.7	-0.8	-1.0	-1.0	-0.8	-0.9	3.5	4.8	1.2	4.1
Panel B: Growth change relative to baseline (%)	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**	**Pre-Crisis Response**	**Post-Crisis Response**
Mean	-8	-8	-11	-11	-9	-10	27	38	9	32
25th Percentile	-9	-9	-12	-13	-10	-11	23	31	8	27
50th Percentile	-8	-8	-11	-11	-9	-10	27	38	10	32
75th Percentile	-6	-7	-9	-9	-7	-8	32	44	11	37

Source: Authors' calculations.