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Estimating the impact of changes in aggregate bank capital requirements on lending and growth during an upswing ☆

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ABSTRACT

This paper estimates the effect of changes in banks' capital requirements on lending by studying the joint dynamics of the historic aggregate capital ratio of the UK banking system and a set of macro-financial variables. This is achieved by means of sign restrictions that attempt to identify shocks in past data that match a set of assumed directional responses of other variables to future changes in capital requirements aimed at increasing the resilience of the banking system to losses during an upswing. This may provide policy-makers with a plausible 'upper bound' on the short-term effects of future increases in macroprudential capital requirements in certain states of the UK economic cycle. An increase in the aggregate bank capital requirement during an economic upswing is associated with a reduction in lending, with a larger effect on lending to corporates than on that to households. The impact on GDP growth is statistically insignificant.

1. Introduction

The recent financial crisis and economic contraction that followed highlighted the crucial role that banks play in facilitating the extension of credit and enabling economic growth. This underlies the economic rationale for imposing regulations on the banking industry, including minimum capital requirements designed to mitigate risks banks would not otherwise account for in their behaviour. A growing international consensus is emerging on the need to re-orientate the regulatory framework to place stronger emphasis on the mitigation of risks in the financial system as a whole.[1] One aim of the Basel III Accord is to raise permanently the level and quality of capital held by banks, in order to improve their ability to absorb loss.

Macroprudential policy also includes provision for dampening cyclical over-exuberance through a regime of risk-weighted capital buffers on top of prevailing *micro*prudential regulatory capital requirements. Such a 'countercyclical capital buffer' could be increased in a credit boom in order to generate greater self-insurance for a system as a whole and act as a restraint on overly exuberant lending.[2] This mechanism could also operate in reverse, with capital requirements being lowered in a bust to provide incentives for banks to increase their lending and reduce the likelihood of a collective contraction in credit exacerbating the downturn and hence banks' losses.

In addition, the Basel III framework is in the process of introducing a simple leverage ratio to act as a supplementary measure to risk-based capital requirements.[3] Whereas risk-weighted capital requirements differentiate capital requirements according to estimates of the relative riskiness of different types of asset, a leverage ratio weights all assets equally. In the UK, the Bank of England's Financial Policy Committee also plans to vary UK banks' regulatory leverage ratio over time, in parallel to changes in banks' risk-weighted countercyclical capital buffer.[4] This is designed to mitigate

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[1] See Financial Stability Board (2011).

[2] See Bank for International Settlements (2010).
[3] See Bank for International Settlements (2014).
[4] See Bank of England (2013).

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risks associated with the excessive expansion in banks' leverage of the sort seen pre-crisis.

These developments have raised the issue of how increases in regulatory capital ratios – both risk-weighted, and their leverage-based counterpart – might affect the broader macro economy. There is a high degree of uncertainty as to how banks might respond to future increases in macroprudential capital ratio requirements, the effect of such responses on the real economy, and how this might vary depending on the prevailing economic circumstances and state of the business cycle. For example, in periods – such as during the recent crisis – where there are concerns about the strength of financial institutions, an increase in macroprudential capital requirements will likely support resilience and lending. For those banks that are perceived by the market to be inadequately capitalised, official action to increase their equity capital will boost resilience and improve market confidence in their solvency. This should reduce their cost of funding, have a positive effect on lending, help arrest the build-up of vulnerabilities created by an overextension of credit and thereby boost banks' resilience.

Conversely, however, in an environment where market participants perceive risks to the financial system to be small, banks may be able to borrow at a rate that is relatively insensitive to how much capital they have. In that case, an increase in macroprudential capital requirements could cause banks' cost of funding to rise. Banks might pass this increase in funding costs on to their borrowers by raising interest rates on loans, and/or reduce the quantity of credit they extend. This might, at least in the short term, lead to a tightening in credit conditions for the real economy.[5]

Estimating the effect of the future operation of a countercyclical capital buffer on economic variables is also complicated by the fact that such a policy tool has never before been used. There are, moreover, very few changes to aggregate regulatory capital requirements observable in past data. And for those changes in regulatory capital that have occurred, it is difficult to isolate how much of the change in bank lending behaviour was as a result of regulation, rather than broader macroeconomic developments affecting the prospects for banks or health of their balance sheets.

The existing literature proposes two broad methods for surmounting this problem. First, one strand of literature attempts to estimate the impact of future macroprudential policy by explicitly representing the dynamics of banks' balance sheets using dynamic stochastic general equilibrium (DSGE) models (BIS (2010) provides a summary). A second seeks to proxy the effect of future changes in macroprudential requirements by performing a 'bottom-up' estimation of the effect of past changes in observable microprudential 'Pillar 2' regulatory capital requirements (Aiyar et al. (2014) and Bridges et al. (2014)). But neither is without caveats. In particular, there are reasons to believe that such positive shocks to individual Pillar 2 capital requirements are an imperfect proxy for increases in capital requirements *affecting all banks simultaneously*, not least given how in the latter case, lending could less easily shift to other banks (or to shadow banks, see Meeks et al. (2014)).

In contrast, the approach offered here seeks to quantify the effect of changes in regulatory capital requirements by studying the 'top-down' joint dynamics of the *aggregate* capital ratio across all UK-resident banks and a set of macro-financial variables, including lending growth. This is achieved by means of sign restrictions that attempt to identify shocks in *past* data that match a set of assumed directional responses of other variables to *future* changes in aggregate bank capital requirements. The same technique is used in the recent monetary policy literature aimed at disentangling the effect of credit demand and supply shocks (De Nicolo' and Lucchetta (2010), Hristov et al. (2011), Gambetti and Musso (2012) and Barnett and Thomas (2014)). But – to the best of the authors' knowledge – this is the first time it has been used to estimate the likely future effect of banks' aggregate regulatory requirements.

In doing so, the analysis here uses data on the aggregate ratio of UK banks' capital-to-assets where assets are not risk weighted; that is, not adjusted by a regulatory risk weight that is designed to capture their relative risk. This differs to the definition of banks' 'capital ratio' as it was originally defined in Basel III, and is instead closer to the definition of the regulatory 'leverage ratio' of capital as a proportion of (unadjusted) assets (or inverse thereof). This means that the effect of a change in bank capital ratios being quantified here is unlikely to correspond directly with a change in risk-weighted requirements.

Our motivations for using non-risk-weighted series are twofold. Firstly, non-risk-weighted series are available over a longer time frame, since risk weights were only introduced in the late eighties after the advent of the Basel I accord in 1988. This extends the length of the available data. Second, they prevent our results being corrupted by any attempts by banks to alter their balance sheets in order to obtain a more favourable regulatory treatment. During the period 1989–2007, UK bank risk-weighted capital ratios rose relative to their non-risk-weighted counterparts, suggesting that banks may have altered their balance sheets, or the models they used to represent their risk, in order to obtain a more favourable regulatory treatment (see Francis and Osborne (2009)). Using a non-risk weighted series may therefore provide a more faithful representation of banks' true leverage, which is immune to such adjustments.

Whilst this empirical focus on changes in banks' leverage ratios means that the results may not be directly applicable to changes in risk-weighted capital requirements (for example of the sort defined in Basel III), they may nonetheless permit insight in the possible effect of time variations in a regulatory leverage ratio, of the type proposed, for example, by Bank of England (2015).

This analysis deals with the case of how an increase in banks' macroprudential capital requirements might affect banks' lending specifically in the face an unsustainable credit boom. In doing so, it assumes that an increase in banks' aggregate regulatory capital represents a negative credit supply shock, and, as such, has a negative effect on the provision of bank lending, at least in the short run. This technique follows from literature examining the effects of shocks to credit supply (see discussion in Hristov et al. (2011)) and provides a 'top-down' complement to 'bottom-up' studies of Aiyar et al. (2014) and Bridges et al. (2014) that find an increase in regulatory capital to be associated with a significant short-run reduction in bank lending growth. In order to identify this type of credit supply shock, an increase in regulatory capital is also associated with an *increase* in issuance of bonds by non-financial firms (as firms substitute their borrowing away from that from banks), and a *decrease* in the return on bank equities relative to that of the rest of the market, reflecting a decline in the profitability of banks as they forego otherwise profitable lending opportunities. Since their introduction by Uhlig (2005), such sign restrictions have proven to be a robust means of analysing the effects of economics shocks and have been widely used in the literature (see Fry and Pagan (2005) for discussion). This is, however, the first time that such an approach has been used to estimate the effects of an increase in regulatory capital.[6]

[5] See Tucker et al. (2013).

[6] It is possible, however, that their use here may conflate the effect of an increase in regulatory capital with that of a broader shock entailing 'bad news' for the financial sector, which is also associated with the same directional response in the other variables. In that case, this methodology would overestimate the effect of an increase in macroprudential requirements.

It is also important to note, however, that the set of sign restrictions assumed here – whereby an increase in capital requirements has a contractionary effect on lending – is likely to apply only during a boom in the extension of credit, such as that witnessed pre-crisis. Indeed, if we adapt the specification used here to remain agnostic on the effect on credit – i.e. by omitting the sign restriction on lending growth – the response of lending to an increase in capital ratios is weakly positive (see Section 4.2). This suggests that the results are highly contingent on the state of the economic cycle.

In particular, they may not match the response of banks to regulation post-crisis, where, for example, high levels of macroeconomic uncertainty might have led market participants to be highly concerned as to banks' vulnerabilities to economic shocks, rendering bank borrowing costs to be highly sensitive to the amount of capital used to finance their lending. Banks may be reluctant to raise capital unilaterally and may not be sufficiently profitable to generate capital organically. But in such circumstances an increase in macroprudential capital *levels* could improve investor confidence in the health of banks, allowing their cost of funding to fall, and thus rendering them able to increase their level of capital without decreasing their lending. Evidence of this can be seen in the bank capital raising that followed the recent US Supervisory Capital Assessment Program (SCAP), which appeared to increase confidence in the banks concerned and allowed them to increase their level of capital and increase their level of lending.[7]

But to the extent that policy-makers concur with the directional response of macroeconomic variables to changes in macroeconomic capital requirements assumed in this model, its outputs may – in certain states of the economic cycle – assist a macroprudential policy maker in estimating the response of macroeconomic variables to changes in future regulation.

In addition, subject to the above caveats, the methodology also provides policy-makers with a plausible 'upper bound' on the short-term effects of future increases in aggregate leverage-based capital requirements – intended to increase resilience in the face of a credit boom. This analysis concludes that an increase of 15 basis points in aggregate capital ratios of banks operating in the UK is associated with a median reduction of around 1.4% points in the level of lending after 16 quarters. The effect is found to be larger on lending to corporates, and less on that to households, perhaps reflecting differences in capital requirements on lending to each.

The text proceeds as follows. The next section introduces the data used in this analysis. A third section briefly reviews techniques used in the existing literature for estimating the impact of changes in regulatory capital before outlining the methodology used here. Section 4 gives some empirical results, and Section 5 extends these to sectoral – as well as aggregate – lending. A final section concludes. Technical working and details of the model and its implementation are confined to the Annexes.

2. A preliminary analysis of bank capital and lending data

This section introduces the bank capital and lending data used in this paper. Results are based on a single series of total bank capital-to-asset ratios across all banks operating in the UK. It is collated from banks' balance sheet reports submitted to the Bank of England. Crucially, this includes the capital ratios pertaining to subsidiaries and branches of foreign banking groups operating in the UK, rather than those of their consolidated group-level entities. It therefore reflects the leverage of all financial institutions lending to UK corporates and households. This series consists of quarterly observations between 1986:Q1 and 2010:Q1 inclusive. Capital here comprises of all ordinary and preference shares constituting banks' share capital (though the results based on a definition of capital as constituting only ordinary shares are unchanged).

UK lending is represented by the real quarterly growth in 'M4 Lending', a measure of UK-operated financial institutions' total lending to private sector firms produced by the Bank of England.

A number of series relating to the wider macro-economy are also included. These include data on real GDP growth from the National Statistics office and Bank of England. Data on bank equity prices, and those of the broader UK equity market, are taken from the FTSE Bank and FTSE All-share indices provided by Datastream. Both series are weighted by the market capitalisations of the underlying issuers. Data on the issuance of corporate bonds by UK private non-financial corporates (PNFCs) is provided on a quarterly basis by Dealogic. Selected time series are shown in Charts 1 and 2. Wider summary statistics are reported in Table 1.

The period 1990–1991 coincided with a notable decline in economic output (see Chart 2), which may explain part of the fall in credit formation during that time. Changes in bank capital are more ambiguous. Bank capital increases steadily during the late eighties, accompanied by a sharp fall in lending. This may in part be due to the increase in capital requirements with the introduction of Basel I in 1988. But it then remains broadly flat between 1990 and 2000.

In contrast, between 2000 and 2007 bank capital ratios decrease steadily as lending expands. This is consistent with the boom in lending having been fuelled by increased bank leverage, one of the proximate causes of the financial crisis often emphasised by regulatory authorities.[8] And the trend reverses itself in the period since the crisis, during which banks' capital ratios have expanded as lending has continued to contract.

It is, however, impossible to observe directly which changes in lending are caused by changes in bank capital regulation. This is the case not only due to the shortage of past changes in bank regulatory requirements, but also because, for those changes that have occurred, it is difficult to isolate how much of the change in bank lending behaviour was as a result of regulation, rather than broader developments (shocks to technology or creditworthiness, for example).

This preliminary analysis of the data therefore reveals the complexity of the task at hand. What is required is some means of isolating changes in lending that are associated with a decrease in the supply of lending by banks that could be reasonably assumed to proxy the effects of a future increase in regulatory requirements.

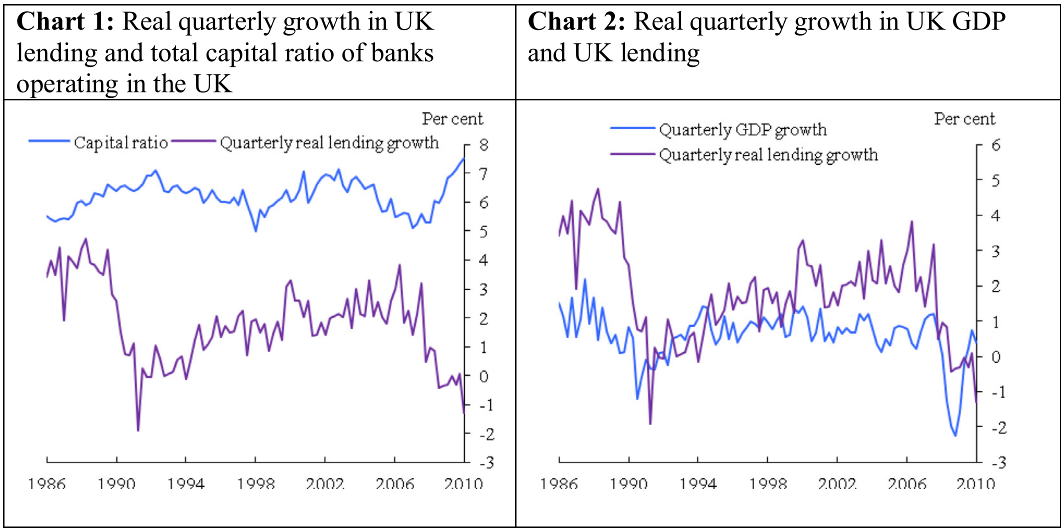
3. Methodology

One approach used to surmount this problem in the existing literature is to use a Vector Auto Regression (VAR) model to estimate the effect of changes in regulatory capital requirements based on the past statistical relationships between capital and other macroeconomic variables. In particular, the approach of Berrospide and Edge (2010) is, in many ways, closest to the approach offered here, in that it estimates a VAR model using 'top-down' data – that is, *aggregate* capital data across all UK-resident banks and other macro-economic variables.

But this use of VAR models fails to adequately disentangle shocks to banks' capital ratios consistent with a change in prudential requirements from those shocks linked to broader macroeconomic developments. For example, some increases in capital ratios present in existing data may plausibly be associated with (or indeed caused by) positive shocks to realised profits – banks end up having higher profits than expected and lend these out.

[7] See Bank of England (2013).

[8] See, for example, Bank for International Settlements (2010).



Charts 1 and 2.

Table 1
Summary statistics: quarterly data, 1986Q1–2010Q1.

	Bank capital:asset ratio (%)	Real M4 lending (£ million)	Real M4 lending growth (%)	Real GDP growth (%)	PNFC issuance (£ million)	PNFC issuance quarterly growth (%)
Mean	6.21	1 054 607.7	1.79	0.59	4 485.05	0.53
Std dev	0.54	626 337.8	1.36	0.71	3 951.10	1.89
Min	4.98	243 640.0	−1.90	−2.25	62.66	−0.83
Max	7.53	2 604 111.0	4.75	2.20	16 453.77	13.67

However, an increase in capital occurring due to increasing requirements may be more nuanced in its effect on lending. In particular, existing studies (such as Bridges et al. (2014), for example) find an increase in microprudential capital requirements to be associated with a material *reduction* in lending to certain sectors. Other than the fact that capital increases in both cases, these two events have little in common.

The failure of existing VAR models to disentangle shocks to capital consistent with changes in prudential requirements may arise as a result of how such VARs typically identify the effect of 'structural shocks' to different variables (in this case to banks' capital ratios) by appealing to the order in which they affect other variables. For example, Berrospide and Edge (2010) assume that structural innovations to the volume of credit can affect bank capital ratios immediately, but that innovations to banks' capital ratios do not have a contemporaneous effect on loans.[9] But such an ordering, which is unable to distinguish between credit demand and credit supply shocks, fails to account for how innovations to bank lending might originate from a shock within the banking sector itself, reflecting a disruption to segments of the financial sector that can impact bank lending contemporaneously. In particular, it fails to account for the sort of friction that might cause banks to react to a change in capital requirements contemporaneously, by, for example reducing their assets.

3.1. Description of methodology used here (a VAR with sign restrictions)

In common with the existing literature, this paper employs a VAR model of the joint dynamics of bank capital and a set of macrofinancial variables. But in doing so, it uses an identification scheme (based on Uhlig (2005)) that imposes sign restrictions on the direction of response of specific variables that might proxy the direction of their response to a change in regulatory capital requirements, at least under certain assumptions. This attempts to address the difficulty, encountered elsewhere in the literature, of distinguishing between changes in bank capital ratios due to an increase in capital requirements versus those due to broader macroeconomic developments.

This approach is of a spirit similar to that used in the monetary policy literature to isolate shocks to credit supply and demand by their differing effects on the price versus the quantity of lending. That is, a reduction in lending due to a reduction in its supply is likely to be associated with an increase in the cost of credit and a decrease in its quantity – whereas a reduction in lending demand is likely to be associated with a reduction in both its cost *and* quantity (see Uhlig (2005), Bean et al. (2010), De Nicolo' and Lucchetta (2010), Busch et al. (2010), and Barnett and Thomas (2014)). But – to the best of the authors' knowledge – this methodology has yet to be used in the context proposed here: that is, in order to identify a shock to capital consistent with a change in regulatory requirements.

In order to implement this approach it is necessary to impose a set of priors as to the direction of movement of other variables in response to a shock in regulatory capital. Doing so is complicated by how there is substantial uncertainty as to how banks could respond to an increase in regulatory capital requirements intended to improve their resilience during a credit boom, and the effect this would have on their lending and on output. For example, banks could respond to tighter regulatory requirements by:

i. Directly reducing their assets (including their stock of existing (and/or flow of new) loans).
ii. Increasing their retained earnings (for example by restricting dividend payments).
iii. Issuing equity.

[9] Other examples of the application of this technique – known as a 'Cholesky identification scheme' – to identify the effect of a shock to banks' capital ratios are provided by Mora and Logan (2010) and Lown and Morgan (2006).

Banks' choice is likely to depend on the relative cost of these three options, which in turn depends on the state of the macroeconomic environment.[10] There is some evidence to suggest that banks' dividend payments are likely to be sticky,[11] and that banks are unlikely to cut remuneration, particularly during an upswing where banks' credit expansion is associated with high profitability. Raising fresh equity may also be more attractive during a boom, but there is some evidence to suggest that equity issuance is costly to banks when it signals that its managers have private information that equity is overvalued (Myers and Majluf (1984)).

An increase in banks' capital need not lead to a reduction in their lending if it does not increase banks' overall cost of funding. But – *to the extent that the resulting increase in banks' funding cost is not fully offset by investors' belief in the banks' reduced risk* (i.e. the Modigliani and Miller (1958) theorem does not hold perfectly) – banks are likely to pass this on to borrowers by raising interest rates on loans or decreasing the quantity of credit they extend by foregoing otherwise profitable lending opportunities. The resulting reduction in the quantity of credit banks extend would therefore be accompanied by a reduction in their return on equity and profitability.[12]

In keeping with this analysis, this methodology assumes that the effect of an increase in banks' regulatory capital mimics that of a broader category of negative credit supply shocks. A negative sign restriction is therefore imposed on the growth in banks' lending, and a positive sign restriction is imposed on the quantity of bond issuance by private non-financial corporates (PNFCs). The latter restriction allows for the isolation of a shock to bank capital from a more general reduction credit demand, and is motivated by how, in the face of a reduction in bank lending as a result of regulatory pressures, non-financial firms might – at least in part – substitute their demand of credit formally obtained from banks to that in private bond markets (Kashyap et al. (1993) develop this idea).

An increase in banks regulatory capital requirements is also assumed to be associated with a reduction in future bank profitability. This reduction in profitability – which is assumed to be specific to the banking sector – is imposed in order to distinguish the effect of a shock to capital requirements from that of any broader negative shock to the prospects for the macroeconomy as a whole. An increase in regulatory capital requirements is therefore assumed to be associated with a negative shock to bank equity prices, relative to that of the entirety of the UK equity market. The overall direction of the effect on GDP is left unrestricted.

Together, these restrictions attempt to identify reductions in bank lending growth consistent with a reduction in bank credit supply and profitability – that is, consistent with a possible transmission mechanism for the effects of an increase in future macroprudential capital requirements during a credit boom. These restrictions, and a summary of their economic justification, are given in Table 2. A detailed description of the methodology and the exact specification used here are given in the Annexes.

This methodology based on sign restrictions therefore allows for the identification of shocks to capital associated with directions of movement in other macro-financial variables that are assumed to proxy those of a change in future regulatory requirements, despite how such policy actions are not present in the past data. It is thereby able to achieve a tighter identification of shocks than that possible using an assumption on the order in which a shock affects variables.

It is not without caveats. In particular, the approach is vulnerable to the 'Lucas critique'. It may be that the relationship between banks' capital ratios and macroeconomic variables of interest *is itself sensitive to the introduction of macroprudential policy*. In a sense, this critique is insurmountable, given that there are no past changes in macroprudential policy. But it does mean that the very strength of this approach – that is, how it quantifies the possible effect of an increase in aggregate bank capital requirements by a macroprudential policy maker, despite this never having occurred previously – is also a potential weakness.

More generally, whatever the assumed set of priors as to the direction of variables' response, the methodology also contains other embedded assumptions. First, it assumes that future changes in regulatory requirements are the sole cause of such changes in bank capital. In reality, banks could increase their capital *voluntarily* – rather than as a result of changing regulatory standards – but in a manner that is still consistent with this direction of movement in other variables. For example, market pressure could plausibly cause banks to increase their level of capital during times of bank stress, with no move in regulatory minima. In addition, any change in regulatory minima may not result in changing capital ratios for banks that are holding a buffer above that minimum requirement. Reductions in lending caused by past voluntary increases in bank capital – if they are associated with the same directional movements in macro-financial variables as specified here (i.e. those consistent with a poorer outlook for bank equities and lending) – will have the effect of increasing our estimated response on lending. Second, the methodology assumes that bank capital would then move one-for-one with such a change in regulatory minima. In contrast, the findings of, for example, Bridges et al. (2014) indicate that, at least in the short term, this may not be the case. Were changes in banks' capital ratios to react more slowly in response to a change in aggregate capital requirements, this would cause the resulting effect on macroeconomic variables to be muted than that given here.

In summary, this methodology provides a useful top-down 'ready-reckoner' of the short-run effects of an increase in aggregate bank capital requirements, based on empirical evidence from the UK,[13] and which provides a complement to the bottom-up studies that have found a negative relationship between regulatory capital and lending growth. But as such, it seems most suited to gauging the effects of an increase in aggregate capital requirements by a macroprudential policymaker *in the upswing*, and before the recent crisis, following which there are reasons to believe the relationship between regulatory capital and lending may vary significantly.

[10] In particular, there may be circumstances where high bank capital ratios *increase* rather than decrease, bank lending growth. For example, the current post-crisis environment gives rise to a high degree of macroeconomic uncertainty, and the increased vulnerability of banks to economic shocks. In such circumstances, an increase in banks' macroprudential capital ratios could improve investor confidence in banks' health, allowing their cost of funding to fall and allowing banks to increase their level of capital without decreasing their lending. For further discussion, see Giese et al. (2013).

[11] See, for example, Haldane (2010).

[12] Note that the degree to which the Modigliani–Miller theorem fails to hold – i.e. the degree to which raising capital is 'costly' for banks – may be state dependent; that is, vary over time. In the upswing, prior to the recent financial crisis, and when bank soundness was not foremost in investors' minds, it may be reasonable that the increase in banks' funding cost that would have come from an increase in regulatory capital requirements would not have been fully offset by increased investor confidence in bank resilience. But following the recent crisis, and the associated bank failures, there may be circumstances in which banks are able to raise equity without decreasing lending. For example, the bank equity capital raising that followed the recent US Supervisory Capital Assessment Program (SCAP) and, in part, the asset quality reviews carried out in some EU countries, appeared to increase investor confidence in bank viability.

[13] The degree to which a reduction in bank loans results in non-financial corporates increasing their borrowing from capital markets (via the issuance of corporate bonds) is likely to vary across jurisdictions and the structure of their financial systems. In particular, the decrease in overall lending that results from an increase in capital requirements (and decrease in bank lending) may be greater in jurisdictions where households and firms are more reliant on the banking sector as a source of credit, compared to in the UK. This may include a number of other jurisdictions within the euro area.

Table 2
Sign restrictions and their economic rationale on the response of variables to an increase in banks' regulatory capital requirement during a credit upswing.

	Sign restriction	Rationale
Lending growth	Decreases	Leading to a reduction in lending caused by a reduction in bank credit supply...
Growth in issuance of bonds by PNFCs	Increases	...the quantity of credit demanded by firms is unaffected and shifts to capital markets...
Bank equity prices (relative to the entirety of the market)	Decreases	...banks profitability decreases because banks forego profitable lending opportunities

4. Empirical results

This section examines the effect of a one period standard deviation (15 basis points) increase in the first difference of the capital-to-asset ratio of banks operating in the UK. Impulse responses are computed for thirty periods. It deals first with results pertaining to the application of the model expounded in Section 4 to the entire sample of data (1986:1–2010:1) on all UK bank operations.

Charts 3 and 4 show the impulse response functions for M4 lending and GDP growth. Full results are shown in Tables 3 and 4. A one period 15 basis point increase in the first difference of the capital ratio is associated with a cumulative increase in capital ratios of around 0.12% points (far-right panel of Table 4). This is associated with a 0.25% point reduction in quarterly lending growth after two quarters, the effect of which fades to zero after around 20 quarters. The effect is significant, at the 16/84th percentiles, for around five quarters.

The range of impulse response functions (IRFs) obtained under this model vary in their interpretation to those under a standard VAR model. The imposition of sign restrictions involves generating a number of different possible responses to our exogenous shock to the capital ratio, and selecting those that meet with our choice of imposed sign restrictions. As discussed in Fry and Pagan (2005), the dark blue lines represent the impulse response functions of the single structural model (the 'Median Target' model) whose impulses are closest to the median responses (see Annex for details). This is important, in that nothing guarantees that the true impulse responses coincide with the median of this distribution, as median responses are not necessarily the 'most probable' responses. The shaded area indicates the difference between the 16th and 84th percentiles (± one standard deviation, assuming this distribution of responses is normal). Error bounds therefore show the uncertainty *with respect to the distribution of outcomes across possible models*, rather than uncertainty surrounding the choice of parameters due to parameter uncertainty as is the case with a standard VAR.

The impact on quarterly GDP growth is insignificant, though the median impulse response function reaches its maximum on impact of −0.08% points after two quarters. This insignificant impact on output is consistent with firms substituting away from bank credit and towards that supplied via bond markets, in response to a reduction in bank lending as a result of an increase in regulatory capital. The overall effect on growth is therefore broadly neutral, consistent with the results of Bernanke and Lown (1991) and Driscoll (2004).

Also of interest are the cumulative impacts of the shock to regulatory capital on the *levels* of other variables, as well as their growth rates. Charts 5 and 6 show the cumulative effect on the *levels* of M4 lending and GDP. The level of lending is reduced by approximately 1.4% after around 17 quarters while GDP is cumulatively reduced by 0.25%.

Lending does not recover to its previous trend. This is consistent with the shape of the median responses of its growth rate, which is negative throughout the observed periods. This suggests that an increase in capital requirements, and its associated effect on lending, causes a reduction in bank lending (though not, given the insignificance of the response of GDP, a reduction in its output).

Chart 7 shows the historical series of 'structural shocks' to the capital ratio, as identified by the single median structural model mentioned above. These are the error terms of the VAR in the 'reduced form' in which it is estimated, combined in the form suggested by estimated relationship between the variables.[14] They are 'structural' in the sense that they represent the meaningful economic relationship the VAR is intended to find – that pertaining to shocks to banks' capital ratios that are consistent with part of the regulatory transmission mechanism studied in this paper. The series is quite noisy, but its eight-quarter moving average – shown in Chart 8 – betrays a more interesting pattern. There are sharp positive shocks to banks' capital around the few episodes of past regulatory tightening, including that in the early 1990s around the introduction of Basel I. This offers some corroboration of the ability of the identification scheme to pick out past changes in regulatory capital, and allow for some faith in its predictive power.

In addition, Chart 8 shows a steady decrease in the average shock to bank capital between the late 1990s and 2006. This may reflect the increase in banks' leverage – in the run up to the recent crisis.

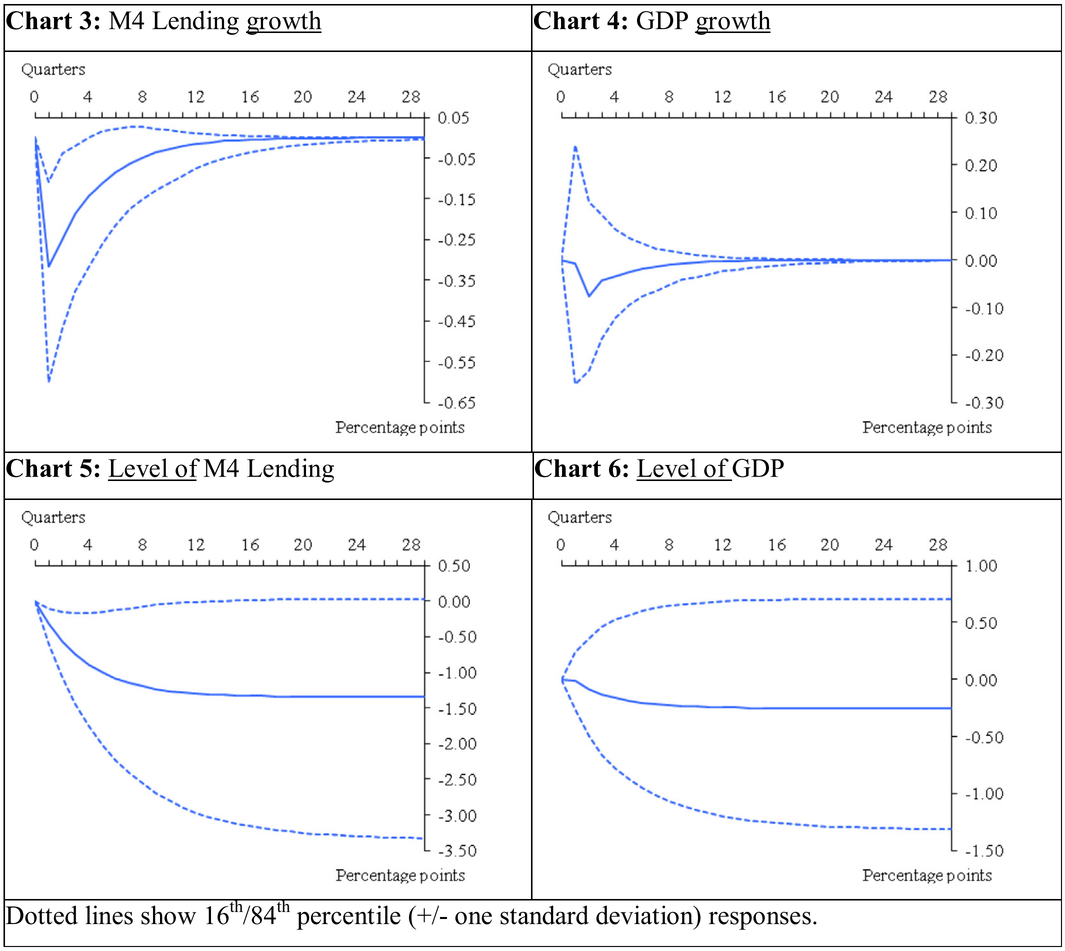
4.1. Counterfactuals

Given these results, it is also possible to compute the counterfactual paths of variables had regulatory capital been increased pre-crisis. This is an interesting simulation exercise, in that it offers policymakers an estimate of how their intervening to increase aggregate capital requirements pre-crisis might have affected lending and output.

The scenario examined here is that in which a macroprudential policy maker had intervened to maintain bank capital ratios at their 2006Q1 level (of just over 6%). This counterfactual capital ratio is *greater* than that actually witnessed pre-crisis, but less than that observed since the crisis. This is illustrated in Chart 9. Intuitively, an increase in macroprudential capital requirements during 2006–7 would have increased bank resilience and reduced the severity of the subsequent crisis.

Charts 11–14 show the range of effects on the growth in, and level of, lending and GDP corresponding to such a policy experiment. This is computed directly from the results above based on the Median Target model and the 16th and 84th percentile responses. The effect of this counterfactual increase in capital ratios is to reduce median quarterly lending growth by up to 1.5% points in 2006–7, but for this effect to be reversed from mid-2008, as the subsequent loosening of capital ratios causes lending growth to 'snap back' and take a value up to 2.7% points greater than that actually witnessed. Whilst the direction of response given by the 16th and 84th percentiles is similar, the dynamic of the 84th percentile is much closer to the observed series.

[14] Algebraically, the structural shocks are the error terms $\{\epsilon_t\}$ of the 'structural' VAR being estimated $By_t = Ay_{t-1} + \epsilon_t$ which are orthogonal (that is, the errors on each variable are uncorrelated). Their estimation amounts to finding matrix B^{-1} so that $\epsilon_t = Bu_t$, where u_t are the (correlated) error terms of the reduced form VAR as it is estimated, that is $y_t = B^{-1}Ay_{t-1} + u_t$.



Charts 3–6. Median impulse responses of a 15 basis point (one standard deviation) structural shock to the *change* in UK bank capital-to-asset ratios (equating to 12 basis point permanent increase in its *level*).

Table 3
Impact of a 15 basis point (one standard deviation) structural shock to the *change* in UK bank capital-to-asset on the *growth* in other variables.

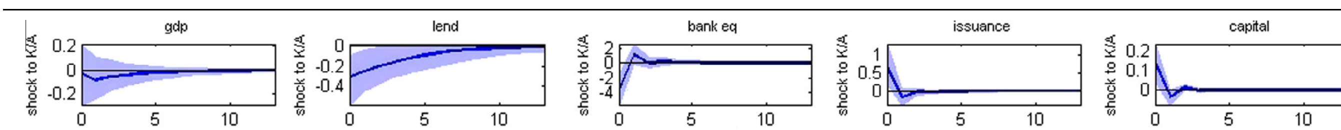
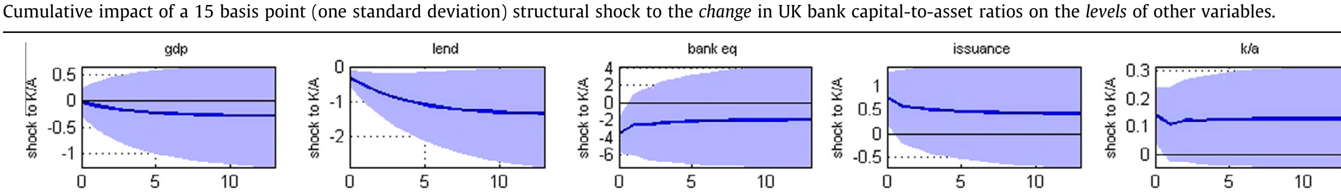


Table 4
Cumulative impact of a 15 basis point (one standard deviation) structural shock to the *change* in UK bank capital-to-asset ratios on the *levels* of other variables.



The overall effect on growth is less marked, with quarterly GDP growth reduced under the median response by up to 0.3% points pre-crisis, and then increased by up to 0.6% points since. And the 16th and 84th percentile outcomes between them encapsulate the opposite direction of response: the 84th percentile response shows growth *increasing* by more than 0.5% points before the crisis and reducing significantly at the end of the sample.

The median counterfactual ratio of credit-to-GDP (Chart 10) is less than its actual outturn during 2006–9; but the resilience of lending means that it shows no decline since.

Under the assumption that a change in macroprudential capital requirements works in the way specified in Section 3, these results indicate that intervention by a macroprudential policy-maker that ‘smoothed-through’ declines and increases in aggregate bank

Chart 7: First-difference in capital ratios: historical shock series

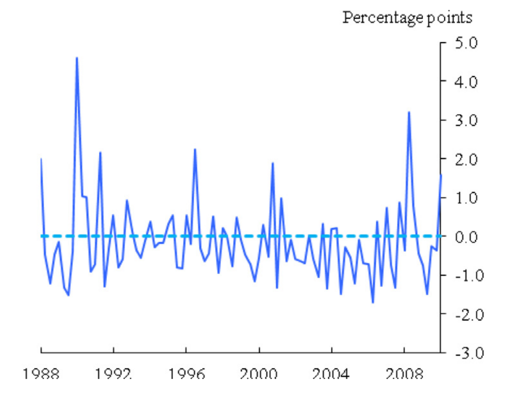
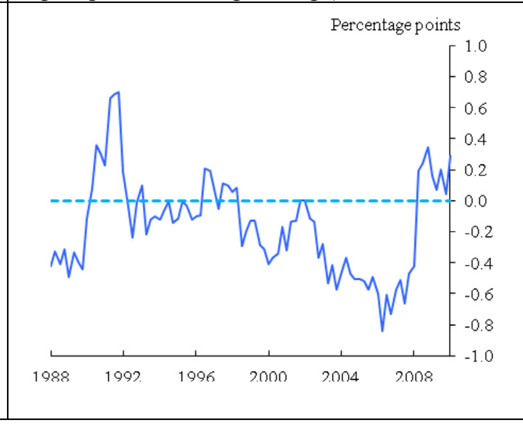


Chart 8: First-difference in capital ratios: historical shock series (backward-looking eight-quarter moving average)



Charts 7 and 8.

capital ratios, might go some way towards reducing the peaks and troughs in the lending and credit-to-GDP cycles.

4.2. Robustness check

Three checks are performed in order to ensure the robustness of these results. First, the model is run across data pertaining to the period 1986:1–2006:4, in order to exclude the most recent data relating to the recent financial crisis. Given the strong divergence in capital and lending since 2007 it is instructive to check whether the crisis period is driving the results. Reassuringly, results based on a sample excluding the crisis period are unchanged, indicating the model's parameters are relative stable over the sample period.

Second, we run a version of the model where the series of issuance by UK PNFCs is substituted for that of UK PNFC corporate bond spreads. Any increase in corporate bond issuance that occurs as firms substitute their borrowing away from credit supplied by banks, may – ceteris paribus – be accompanied by a fall in the value of corporate bonds (and a rise in their spread) as their supply is increased. This is in the spirit of the restrictions used in a monetary policy VAR, where a decrease in the supply of bank credit is identified by its opposing effects on the direction of the *price* – that is, the lending *rate* – as well as the *quantity*, of. The corporate bond spreads serve as a proxy for the lending rate since it represents the funding cost of banks which then re-direct to their customers. Results are more-or-less invariant to this change (Charts 15 and 16).

That the cost – as well as the quantity – of PNFC bond issuance rises in face of an increase in regulatory capital requirements (as identified under this framework), is, therefore, in one sense an encouraging cross check on the veracity of our results. However, it does raise the conundrum of why such a shock to capital is associated with only an insignificant effect on growth: it might be natural to assume that any increase in the cost of credit to be associated with depressed output, as firms are unable to borrow as cheaply to take advantage of profitable investment opportunities. One potential explanation, also discussed in Bernanke and Lown (1991) and Driscoll (2004) in the context of US banks, may lie in the role of the non-bank entities, who are able to extend credit to corporates despite lying outside the scope of the regulated banking system (and hence of the lending data used in this study). Such 'shadow banking' entities may, in the face of a constriction of bank credit, substitute for banks by lending to PNFCs, thus reducing the potential impact on output.

Finally, a version of the model was calibrated that omitted the sign restriction on lending growth, so that only the direction of the response of bank equity returns and bond issuance was specified, but that of lending growth was left unrestricted. Under this alternative identification scheme, the response of lending to a positive shock in capital ratios was weakly positive, though not with any significance. This suggests that the results presented here are compatible with only *one* potential transmission mechanism for macroprudential capital requirements – i.e. that involving to a decrease in bank lending growth – that perhaps best matches the behaviour of banks in the upswing, and when banks' cost of debt is insensitive to improvements in banks' solvency. It is likely that, in other circumstances, the directional response of lending and output growth could be different (see Giese et al. (2013)).

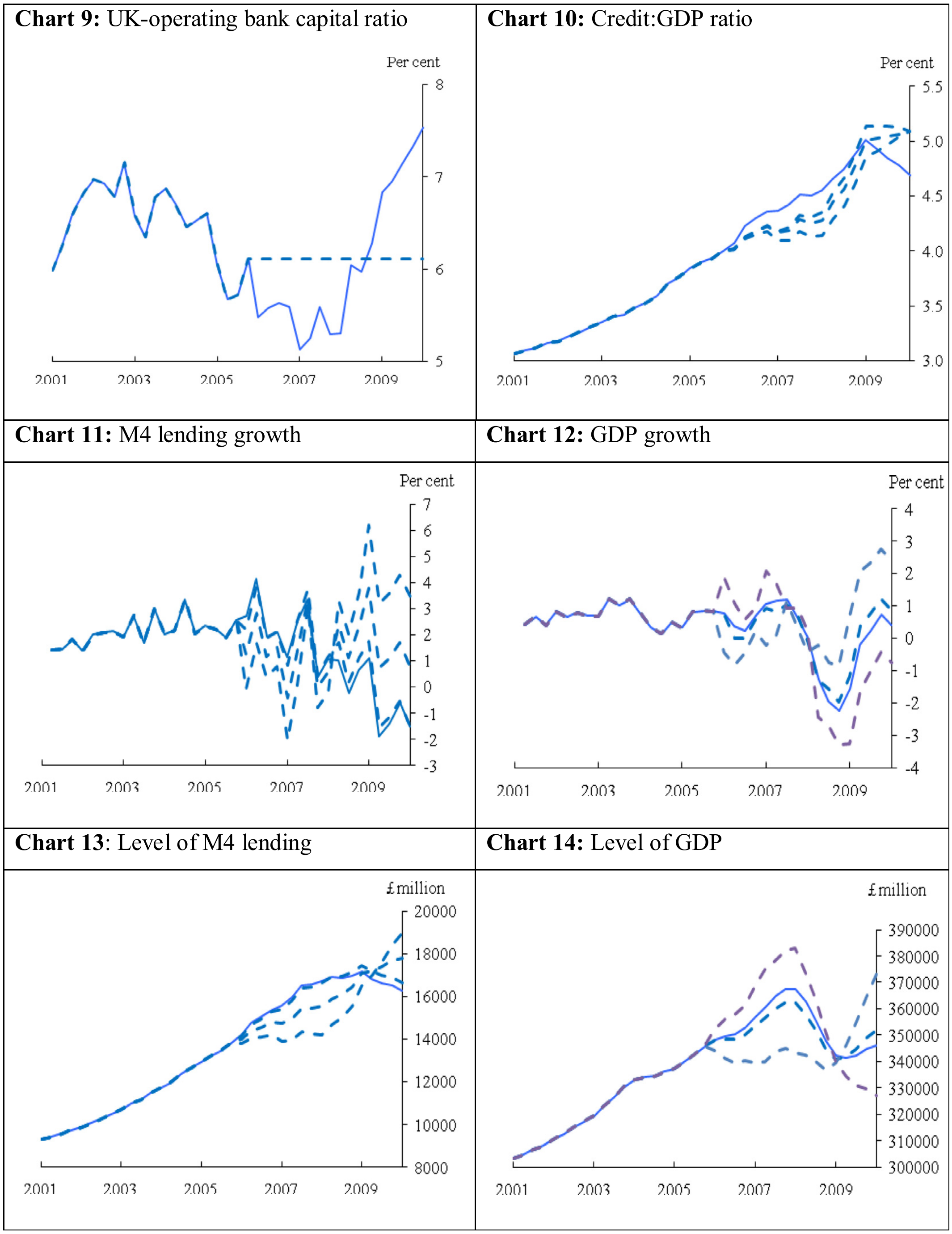
4.3. Comparison of these results to those elsewhere in the literature

Comparison of these results to those elsewhere in the literature is frustrated by how, while this methodology is based on a leverage-based measure of banks' capital ratios, the majority of those in the wider literature tend to be risk-based. In order to convert the results described above to those comparable with a change in banks' aggregate risk-weighted capital requirement, we assume an average risk weight across UK banks' assets of 50%.[15] On this basis, the median results of this methodology – when appropriately scaled – imply that a one percentage point increase in risk-weighted capital requirements are associated with a 0.85% point reduction in growth, and a 4.5% cumulative reduction in the long-run level of lending.

This is a larger reduction in lending than that found in other 'top down' studies such as Francis and Osborne (2009) and Cosimano and Hakura (2011), which find an equivalent reduction in the volume of lending of only 1.2/1.3% respectively. This may be as a result of how our identification scheme based on sign restrictions may conflate a regulatory shock with a broader shock entailing 'bad news' to the financial sector, thus overestimating the effect of an increase in regulatory capital requirements.

Comparison with the impact found by the analysis of Bridges et al. (2014) is less straightforward, and varies across sectors. Bridges et al. find a 1% point increase in risk weighted capital requirements to have a 0.77% point initial reduction in secured

[15] For justification of this assumption and details of the methodology supporting it, see IMF (2012).



Charts 9–14. Counterfactual paths of M4 and growth, had banks' regulatory capital requirements been held at 6.1% from 2006:1. Solid lines show actual data; dotted lines show counterfactuals corresponding to the 50th, 16th and 84th percentile responses.

household lending *growth*, a result comparable to that found here. The median response to the same shock in *un*secured household lending is smaller, with only a 0.19% point reduction in growth after five quarters. However, an equivalent shock to capital requirements on lending to non-financial corporates produces a 4.0% point reduction in lending growth, which is larger both than the effect on growth of lending to other sectors in the same study, and on that found here. The range of responses in lending growth across different sectors might reflect how – rather than consider the effect of higher capital across banks *in aggregate*, as we do here – Bridges et al. base their study on *individual* ('Pillar 2') capital requirements. Increases in such capital requirements to different sectors might, historically, have come about as a result of increases in the risk of specific banks' exposures to these sectors. It therefore seems natural that the response of lending might, in certain cases, be more pronounced.

5. A 'satellite' model of the effect on lending to different sectors

Also of interest is how a change in aggregate bank capital requirements – such as that instigated by a macroprudential policymaker – would affect bank lending to different sectors of the

Robustness check: an alternative specification with PNFC corporate bond *spreads* in place of issuance volumes

Chart 15: Impulse response of M4 Lending growth to a 15 basis point shock to the *change* in UK bank capital-to-asset ratios

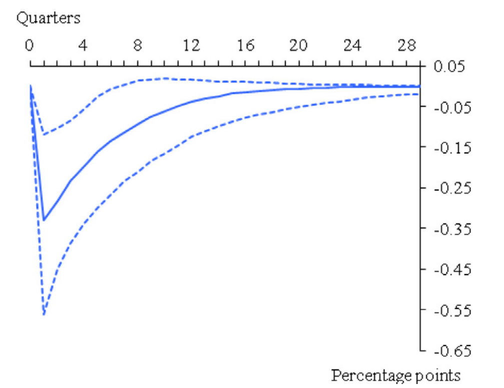
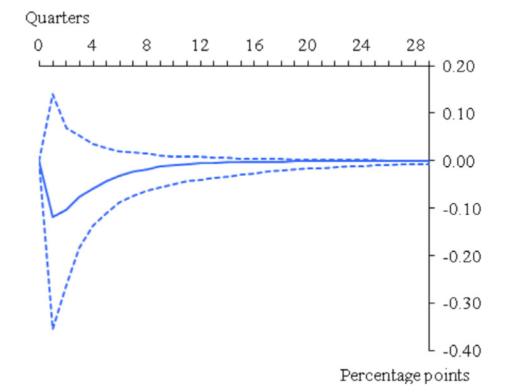


Chart 16: Impulse response of GDP growth to a 15 basis point shock to the *change* in UK bank capital-to-asset ratios



Dotted lines show 16th/84th percentile (+/- one standard deviation) responses

Charts 15 and 16.

economy. One of the powers of the FPC is to direct a change in sectoral capital requirements.[16] This would allow it to direct an increase in capital requirements towards a specific sector of the economy, and the vulnerabilities contained therein, in the event that it judged this to be a more effective means of increasing the resilience of banks given their exposures to that sector than an increase in aggregate capital requirements. The analysis here, however, focuses on the impact on different sectors of an increase in aggregate capital requirements during an upswing in the credit cycle.

Ideally, sectoral lending series could be included in the VAR alongside those of aggregate lending, in order to compare their interactions with a shock to capital ratios. However, as described in Section 4.3, this would create an identification problem, in that the number of variables to be estimated in the VAR would then be too large, relative to the number of observed data points.

An alternative means of investigating the effect of the shock to capital ratios explored here on lending to different sectors, is to examine their relationship with the series of historical structural shocks produced by the VAR using aggregate data (see Chart 8). This approach takes the results of the VAR 'as given', assumes they represent a reasonable proxy of the shocks the approach is seeking to capture (i.e. those consistent with changes in macroprudential capital requirements), and forms some 'satellite' model of their relationship with sectoral lending.

This 'satellite model' involves the regression of series of changes in lending to different sectors, on lagged values of that series, along with the structural shock.[17] That is:

$$\text{Sectoral\_lending\_growth}_t = \alpha * \text{Sectoral\_lending\_growth}_{t-1} + \beta * \text{structural\_shock}_t + \varepsilon_t$$

This is performed for the series of lending growth in each sector separately. Results are shown in Table 5, the rows of which show the regression coefficients corresponding to lending to each sector: households, private non-financial corporates (PNFCs), and

Table 5
A regression of sectoral M4 lending growth on the series of structural shocks.

Sector	Coefficient on: (*p* values are shown in brackets)	
	Lagged sectoral lending growth (α)	Contemporaneous structural shock (β)
PNFC	0.7462 (*0.0001*)	−0.641 (*0.0003*)
CRE	0.7091 (*0.0055*)	−0.8150 (*0.0032*)
Non-CRE	0.2868 (*0.0051*)	−0.333 (*0.0043*)
Households	0.9116 (*0.0001*)	−0.262 (*0.0001*)
NIOFC	0.4801 (*0.0151*)	−0.8163 (*0.0398*)

non-intermediary other financial corporates (NIOFCs). As might be expected, given the nature of the credit cycle, coefficients of lagged lending growth to its contemporaneous value are positive across all sectors. Growth in lending to PNFCs is also split into lending to firms in the commercial real estate (CRE) sector and that to other PNFCs.[18] The coefficients on the contemporaneous structural shock are negative, reflecting how an increase in capital requirements is associated with a reduction in growth in lending to each sector, as well as that in aggregate.

Chart 17 shows the resulting impulse responses of growth in lending to PNFCs, households and NIOFCs. These are calculated by considering the effect of a one-standard deviation increase in capital ratios on *aggregate* bank lending (as in the previous section), and computing the effect on the growth of lending to each sector in a single period via the coefficient on the structural shock (the final column of Table 5). The effect of this shock over subsequent quarters – i.e. how it 'fades' over time – is then found via repeated multiplication of the regression coefficient on the lagged value of each series.

The relative size and shape of these impulse response functions is informative as to the relative strength of the effect of regulation on lending to different sectors. The effect on lending to households appears far weaker than that to PNFCs, with the maximum

[16] See Bank of England (2013).
[17] Initial regressions included a constant term, along with lagged values of the structural shock; but these were excluded on the grounds that the resulting regression coefficients were insignificant.
[18] PNFC non-CRE lending is calculated as PNFC lending less CRE lending. Due to differences in definitions, especially related to a reclassification of housing associations, this measure tends to be less precise than that of CRE lending.

Chart 17: Impulse responses of a 15 basis point (one standard deviation) shock to the change in UK bank capital-to-asset ratios on growth of lending to different sectors

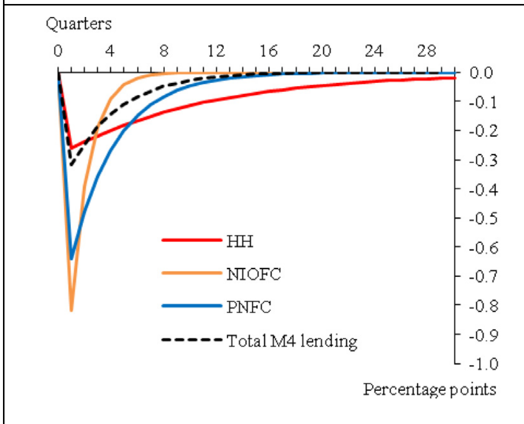
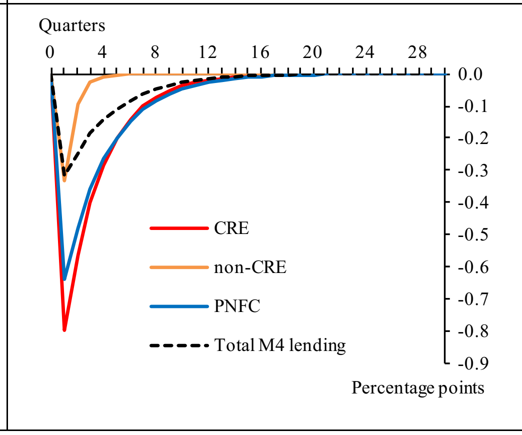


Chart 18: Impulse responses of a 15 basis point (one standard deviation) shock to the change in UK bank capital-to-asset ratios on growth of lending to CRE and non-CRE PNFCs



Charts 17 and 18.

reduction in the growth of lending to PNFCs being around three times that to households. This is consistent with the findings of Bridges et al. (2014), who find a lower reduction in the growth of secured/unsecured lending to households, compared with that to CRE/non-CRE PNFCs. The difference in effect between the two sectors may arise because the risk weights on banks' lending to households, which tends to have a lower write-off rate of loans where the borrower cannot repay, are lower than those on lending to corporates, meaning that a change in macroprudential regulation causes banks to reduce household lending less than that to other sectors. For example, the average risk weight on mortgages issued to UK households is less than that on the average corporate loan.[19] This is also corroborated by the shape of the impulse response functions. The effect on the growth of lending to households, although smaller, takes around twice as long to fade to zero as that on other sectors. This is consistent with how lending to households, at least in the form of mortgages, is likely to be of a longer term than loans to corporates, meaning that its adjustment in response to a change in capital requirements will occur more slowly.

Chart 18 shows the differing responses of the growth in lending to CRE and non-CRE PNFCs. The response of lending to CRE is far stronger, with the maximum reduction in lending growth in the first quarter being around two-and-a-half times that to non-CRE firms (similar to the finding of Bridges et al.). This may also be attributable to the higher regulatory risk weight applicable to banks' lending to CRE firms, compared to that of other PNFCs, which may cause them to retract lending to CRE more readily when faced with an increase in regulatory capital requirements.

That said, the strength of this response of lending to CRE does raise the issue of endogeneity. It is possible that, for example during the crisis, reductions in lending to commercial real estate – a product, perhaps, of sharply declining prospects for the future profitability of this sector – themselves resulted in increases in bank capital following the losses banks incurred on their lending.[20] Such endogeneity issues are the inevitable consequence of the simplistic satellite model employed here.

[19] Under the standardised approach of Basel II, lending to corporates receives a 100% risk weight, while that to households receives a risk weight of between 35% and 100% (depending on the level of loan collateralisation).

[20] For further discussion, see Benford and Burrows (2013).

6. Conclusion

This paper provides an estimate of the possible effect of future changes in aggregate regulatory capital requirements – such as those instigated by a macro-prudential policy maker – on the macro economy during an upswing in the credit cycle. Specifically, it uses a VAR-based approach to identify shocks to capital in the past data whose associated movement in other macro variables matches one set of possible priors as to the expected response to future changes in macroprudential capital requirements during a credit boom. This is achieved using a methodology that restricts the direction of the response on other variables, allowing for the isolation of shocks to capital ratios associated with a decrease in lending, decrease in bank equity prices (relative to the remainder of the market), and a substitution by firms away from bank funding to that via capital markets. As such, it provides a 'top-down' complement to the bottom-up studies that have found a negative relationship between regulatory capital and lending growth.

This analysis concludes that an increase of 15 basis points in aggregate leverage-based capital ratios of banks operating in the UK is associated with a median reduction of around 1.4% in the level of lending after 16 quarters. These results may be of use to a macroprudential policy maker, and may offer a 'upper-bound' as to the short-term effect of future changes in system-wide capital requirements, at least in the upswing of the credit cycle and in the UK, and under the assumption that capital requirements bind. The impact on quarterly GDP growth is statistically insignificant, a result that is consistent with firms substituting away from bank credit and towards that supplied via bond markets or via shadow banking entities.

There are numerous possible future extensions to this work. The model used here could be expanded to include data on lending to different sectors, or to incorporate lending via financial intermediaries outside the regulated banking sector (eg 'shadow banks'). Furthermore, it could be expanded to estimate the affect of changes in capital requirements on lending to a more granular set of institutions, including banks' foreign lending. This would allow for the investigation of the possible spill-overs from an increase macroprudential capital requirements in one jurisdiction on lending to another. It could also be expanded to estimate the effect of other macroprudential regulatory tools, including changes in liquidity requirements.

Such extensions, would, however require a substantial increase in the number of variables in the VAR, and so may necessitate the use of more complex estimation strategies, including those of a Bayesian VAR. They are, therefore, left as further work.

Appendix

Annex 1: General description of a structural vector auto regression

A Structural Vector Auto Regression (SVAR) model can be defined as follows:

$$Bx(t) = A(0) + A(1)x(t-1) + A(2)x(t-2) + \ldots + A(p)x(t-p) + \varepsilon(t)$$

where $x(t)$ is a (n-by-1) vector of n endogenous variables; $x(t-1)$, …, $x(t-p)$ are vectors of lagged endogenous variables; B, $A(1)$, …, $A(p)$ are (n-by-n) matrices of coefficients; $A(0)$ is a (n-by-1) vector of constant terms and $\varepsilon(t)$ a (n-by-1) vector of structural innovations assumed to be normally distributed (that is, $\varepsilon(t) \sim N(0, I_n)$).

Since the left-hand side of the equation above implies that each variable is influenced by the contemporaneous values of all the others, the SVAR cannot be estimated directly since this would violate an assumption used by standard estimation techniques that regressors have to be independent of the error term.

For estimation purposes the VAR can instead be rewritten in reduced form by pre-multiplying both sides of the structural equation by B^{-1}:

$$x(t) = C(0) + C(1)x(t-1) + C(p)x(t-p) + u(t)$$

where $C(0) = B^{-1}A(0)$ is a vector of constants; $C(1) = B^{-1}A(1)$, …, $C(p) = B^{-1}A(p)$ are matrices of coefficients of the p lagged values of the variables; and $u(t) = B^{-1}\varepsilon(t)$ is the reduced form error term. This model can be estimated equation-by-equation via ordinary least-squares.

Since the reduced form residuals $u(t)$ are a linear combination of the structural residuals $\varepsilon(t)$, they are correlated with each other, i.e. their variance-covariance matrix $\sum$ is not diagonal. This implies that a shock to one will trigger shocks to others.

In order to identify the effect of an exogenous shock on one variable to the dynamics of the others, it is necessary to recover 'structural' parameters of the model by imposing restrictions on the reduced form model. Recalling that $E[\varepsilon(t)\varepsilon(t)'] = I_n$ and $E[u(t)u(t)'] = \sum$, this amounts to finding a matrix A (the 'impact matrix') such that $u(t) = A\varepsilon(t)$ and $AA' = \sum$. One way to obtain A is to consider the Cholesky decomposition of the matrix $\sum$.

In order to impose the sign restrictions on the resulting impulse responses (as given in Table 2) we compute candidate impact matrices by drawing n-by-n matrices K whose elements are $N(0,1)$ and then decompose this matrix so that $K = QR$. Q is an orthogonal matrix (i.e. $QQ' = I$) so that $\sum = AQQ'A'$ forms another plausible decomposition of the variance covariance matrix and $A' = AQ$ is a new candidate impact matrix (see Rubio-Ramirez et al. (2007) details of this methodology). We repeat this procedure 1500 times and retain the impact matrices A' that satisfy the sign restrictions and discard those that do not.

Each retained impact matrix A' allows for the generation of set of impulse response functions across each variable that satisfy the scheme of imposed sign restrictions. There will therefore be many candidate impulse response functions that may be indexed by different numerical values of the parameters of the impact matrices; let each be denoted $\theta^{(l)}$. As observed in Fry and Pagan (2005), however, the model that produced the median one variable may not be the model that produced the median response for another. Presenting the median response for each variable separately therefore gives a potentially misleading indication of central tendency of the results across multiple variables.

As a solution, this work therefore follows the Median Target Method suggested by Fry and Pagan (2005). This isolates a single structural model – the Median Target model – whose responses are as close as possible to the median impulse response function for each variable. To find the Median Target model the impulse response functions are first standardised by subtracting their median and dividing by their standard deviation. The standardised responses are then placed in a vector $\varphi^{(l)}$ for each value of $\theta^{(l)}$ and l is chosen to minimise $\varphi^{(l)'}\ \varphi^{(l)}$.

Annex 2: Specification for the implementation used here

The SVAR considered here involves the following five quarterly variables over the period 1986:Q1–2010:Q1:

- GDP growth.
- M4 lending growth.
- The ratio of returns on UK FTSE banks relative to those on the broader FTSE All Share Index (bank equity 'beta').
- Issuance of bonds by private non-financial corporates (PNFCs).
- The aggregate capital-to-asset ratio for UK operating banks.

The first four variables are expressed in growth rates and the capital-to-asset ratio in first differences in order for the series to be stationary. An initial specification used variables in levels rather than differences/growth terms, but this resulted in a infinite response of variables to the shock under study (i.e. the eigenvalues of the matrix of estimated coefficients from the VAR had eigenvalues of absolute value greater than one); considering growth in/first differences of variables circumvented this problem.

A single lag is used in the VAR. This is selected to give the best behaviour of residual error terms as judged by standard information criteria – that is the minimisation of the Akaike and Bayesian Information criteria.

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