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Abstract

This paper estimates the effect of changes in capital requirements applied to all UK-resident banks on lending by studying the joint dynamics of the 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 policymakers with a plausible 'upper bound' on the short-term effects of future increases in macroprudential capital requirements in certain states of the economic cycle. An increase in the aggregate bank capital requirement during an economic upswing is associated with a reduction of lending, with the effect larger for lending to corporates than for that to households. The impact on GDP growth is statistically insignificant.

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

JEL classification: G21, G28.

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Summary

This paper estimates the effect of changes in capital requirements applied to all UK-resident banks' aggregate capital requirements on lending during a credit boom. It is a 'top-down' study that investigates the joint dynamics of the aggregate capital ratio of UK-resident banks and a set of macro-financial variables, including lending growth. Its results may be useful to policy-makers given the growing international consensus on the need to apply time-varying macroprudential bank capital requirements on top of existing microprudential requirements. An example is the countercyclical capital buffer that comprises part of the toolkit of the Bank of England's Financial Policy Committee (FPC).

Estimating the effect of an increase in aggregate bank capital requirements on the macro economy is complicated by how 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 requirements that have occurred, it is difficult to isolate how much of the change in bank lending behaviour was as a result of those changes, rather than broader macroeconomic developments affecting banks. The approach offered here surmounts this problem by identifying shocks in past data that match a set of assumed directional responses of other variables to future changes in banks' aggregate capital requirements.

This analysis estimates how an increase in macroprudential capital requirements might affect banks' lending in the face a credit boom. In doing so, it assumes that an increase in banks' capital requirements have a negative effect on the supply of bank lending, at least in the short run. It is also important to note, however, that this assumption is likely to hold true only during a boom in the extension of credit, such as that witnessed before the recent financial crisis. It may not match the response of banks to regulation after the crisis, when, for example, an increase in macroprudential capital levels could improve investor confidence in the health of banks, allowing their cost of funding to fall, and thus enabling them able to increase their level of capital without decreasing their lending.

The estimates of the impact of aggregate capital requirements on lending may – in certain states of the economic cycle - provide policy-makers with a plausible 'upper bound' on the short-term effects of future increases in macroprudential capital requirements. This analysis concludes that

an increase of 15 basis points (one standard deviation) in the aggregate capital ratio of the UK banking system is associated with a median reduction of around 1.4 percentage points in the level of lending after 16 quarters. The effect is found to be larger on total bank lending to corporates, and less on that to households, perhaps reflecting differences in capital requirements on lending to each sector. 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 capital buffers on top of prevailing *micro*prudential regulatory capital requirements. Such a 'countercyclical capital buffer' is part of the Basel III accord and also part of the toolkit of the Bank of England's Financial Policy Committee (FPC).[2] The 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. 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. A sectoral capital requirement also allows the FPC to change capital requirements on exposures to specific sectors of the economy.[3]

These developments have raised the issue of how increases in regulatory capital ratios are likely to 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 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

[1] For example see Bank of England (2009) and Financial Stability Board (2011).
[2] See Bank of England (2013).
[3] For further discussion of the potential operation of a countercyclical capital buffer see Bank of England (2013).

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, helping to arrest the build-up of vulnerabilities created by an overextension of credit.[4]

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* (2011); 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)).

[4] See Tucker *et al*. (2013).

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), Barnett and Thomas (2013)). 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 an aggregate ratio of bank 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 is usually defined in regulatory circles (including the macroprudential capital buffer) and is closer to the definition of the regulatory 'leverage ratio' of capital as a proportion of (unadjusted) assets (or inverse thereof). This means that the change in bank capital ratios being quantified here is not directly equivalent to a change in *regulatory capital requirements;* however, this has the advantage of allowing the use of aggregate data over a longer time period, which pre-dates the introduction of regulatory risk weights. Moreover, it may provide a more faithful representation of banks' true leverage, which is immune to attempts of balance sheets' manipulation in order for banks to obtain a more favourable regulatory treatment (see Francis and Osborne (2009)).

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 has a negative effect on the provision of bank lending, at least in the short run. It 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* (2011) 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.[5]

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 by omitting the sign restriction on lending growth, the response of lending to an increase in capital ratios is weakly positive (see Section 5.2). 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.[6]

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

[5] 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' to 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.

[6] See Bank of England (2013).

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 capital requirements – intended to increase resilience in the face of a credit boom - that compliments that of 'bottom-up' methodologies (including Bridges *et al* (2014)). 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 percentage 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 the methodology used here is introduced in the forth section. Section 5 gives some empirical results, and Section 6 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 an Annex.

2 A preliminary analysis of bank capital and lending data

This section introduces the bank capital and lending data used in this paper and performs a preliminary 'eyeball analysis' of its historical movements in trends prior to any more in depth investigation. Its motivation is two-fold. First, a simple inspection of the data itself reveals stylised facts that are relevant to our analysis: for example, the increases in lending and fall in bank capital ratios prior to the recent crisis, with a reversal of this trend in recent years. Second, the lack of a clear relationship between bank capital and lending over the entire sample indicates the challenging nature of the task at hand. In particular, it is difficult to tell the extent to which changes in lending are driven by changes in the demand for, as opposed to the supply of, credit by banks, let alone a change in capital requirements.

Chart 1: Real quarterly growth in UK lending and total capital ratio of banks operating in the UK

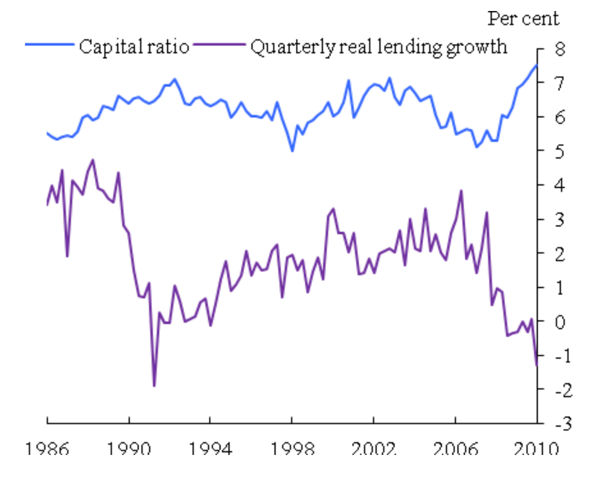
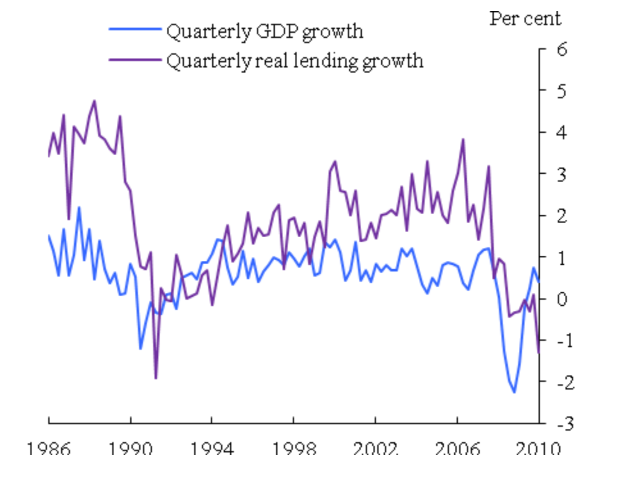


Chart 2: Real quarterly growth in UK GDP and UK lending



2.1 Data and definitions

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).

For the purpose of this analysis, assets in the denominator of this capital ratio series are not risk weighted. This means they exclude the effect of risk-weights applied under the 1988 Basel I regulatory accord, which were designed to reflect the varying likelihood of a bank experiencing loss on its different assets. The resulting 'risk weighted' capital ratios are intended to give some indication of the degree of bank capitalisation *relative* to the risk of their assets.

Table 1: Summary statistics: quarterly data, 1986Q1 – 2010Q1						
	Bank capital:asset ratio (per cent)	**Real M4 lending (£ million)**	**Real M4 lending growth (per cent)**	**Real GDP growth (per cent)**	**PNFC issuance (£ million)**	**PNFC issuance quarterly growth (per cent)**
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

Table 2: Contemporaneous correlations			
	Bank capital:asset ratio	**Real M4 lending growth**	**Real GDP growth**
Bank capital:asset ratio	1.00	-0.40	-0.27
Real M4 lending growth	-0.40	1.00	0.49
Real GDP growth	-0.27	0.49	1.00

Chart 3: Quarterly growth in issuance of bonds by UK private non-financial sector firms

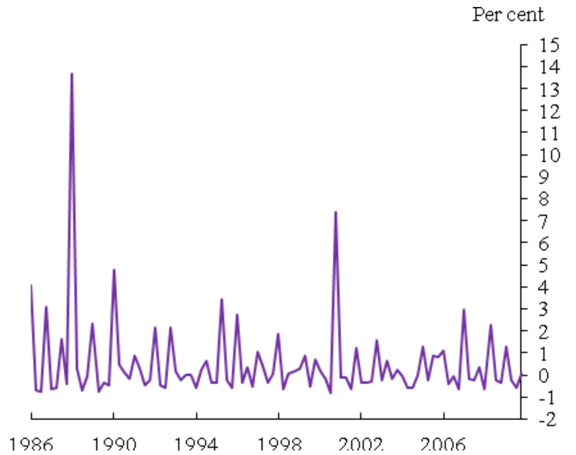
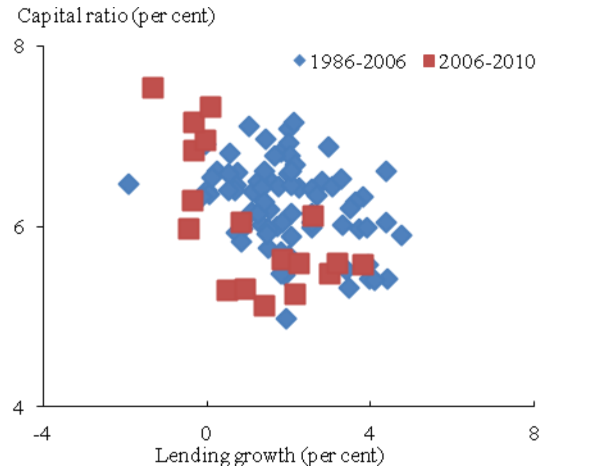
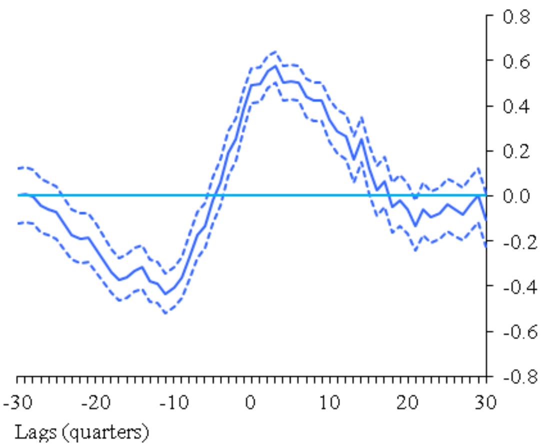


Chart 4: Real quarterly growth in UK lending versus total UK-operating bank capital ratio, over different time periods



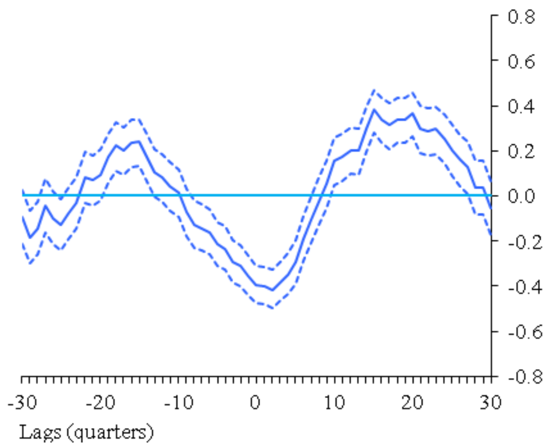
Our motivations for using non-risk-weighted series are two-fold. Firstly, non-risk-weighted series are available over a longer time frame, since risk weights were only introduced in the late eighties after the advent of the Basel I accord in 1988. This extends the length of the available data. Second, 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.

Chart 5: Correlation between lagged lending growth and contemporaneous GDP growth[(a)]



(a) Correlation between lending growth at period *t + lags* and GDP growth at periods *t*.

Chart 6: Correlation between lagged capital ratios and contemporaneous lending growth[(a)]



(a)Correlation between capital ratio at period *t+ lags* and lending growth at periods *t*.

Dotted lines show 16th/84th per cent significance levels.

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. Summary statistics are reported in Table 1.

2.2 A commentary on lending and bank capital since 1977

A preliminary inspection of the data on UK lending growth and bank capital reveals an ambiguous relationship between the two. The series are shown in Chart 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.[7] And the trend reverses itself in the period since the crisis, during which banks' capital ratios have expanded as lending has continued to contract. The change in behaviour witnessed during the recent crisis is illustrated in Chart 4, which shows a scatter plot of lending growth against bank capital ratios. The red squares split out the data points since 2007, and show a stronger negative correlation than that present across the wider series.

Table 2 shows contemporaneous correlations between the capital ratio, lending and GDP growth series. Chart 5 shows the correlation of lagged lending and contemporaneous GDP growth: that is the correlation between lending growth in period $t + lag$ and GDP growth in period t, where *lag* is on the x-axis. Chart 6 gives that of the lagged capital ratio and contemporaneous lending growth.

These correlations are quite instructive as to the role that bank capital and lending play in facilitating growth. As might be expected, contemporaneous lending and GDP growth are positively correlated. Lending growth in any period is *most* correlated with GDP growth four quarters before, perhaps suggesting some form of 'overhang' in the supply of credit that allows it to feed into firms with a lag. This could be due to firms arranging credit lines with banks during periods of high growth which they are then able to draw upon later, including in a later downturn. Banks' capital ratios and lending are negatively correlated, suggesting that higher bank leverage is associated with greater credit extension. Together these patterns seem to confirm that in the upturn, banks 'leverage up', expanding their balance sheets to increase lending but increasing their risk in the process. The correlation of the lagged capital ratio and

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

contemporaneous lending growth is shown in Chart 6, and appears to confirm a counter-cyclical relation between the two.

But while these aggregate series point to some possible reasons for changes in credit observed over the sample, it is difficult to tell the extent to which they were driven by a change in the demand for credit as opposed to its *supply* by banks, *let alone a change in capital requirements.* Not only are there few changes to aggregate regulatory capital requirements observable in past data; but, 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 macroeconomic developments.

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 Existing attempts to identify the effect of an increase in regulatory capital requirements

The existing literature contains various methods for estimating the effect of an increase in regulatory capital requirements that attempt to circumvent this lack of observable changes in such capital requirements in the past data. None are without shortcomings.

Some approaches attempt to model the dynamics of variables relating to both banks' balance sheets and other macroeconomic variables, and extract from the relationship between them a plausible estimate of how some structural shift in the former (caused, for example, by increasing capital requirements) would affect macroeconomic variables of interest.

The first of these is based on dynamic stochastic general equilibrium (DSGE). These have the advantage of positing dynamic relationships between variables of interest that are grounded in microeconomic theory but come with the significant limitation of offering a heavily stylised view of banks' balance sheets that is typically insufficiently nuanced to capture the dynamics of real-world data. In addition, fitting DSGE models to observable data is still quite challenging, even when using sophisticated econometric and statistical methods (BIS (2010) provides a good summary of the current approaches and their pitfalls.

A second strand of literature seeks to proxy the effect of future changes in macroprudential requirements by estimating the effect of past changes in observable *micro*prudential 'Pillar 2' regulatory capital requirements on a panel of UK banks (Aiyar *et* al (2011); Bridges *et al* (2014); Francis and Osborne (2009)). There are, however, reasons to believe that such shocks to individual bank capital requirements are an imperfect proxy for capital requirements affecting all banks simultaneously (ie. those due to a change in macroprudential requirements). In response to a reduction in lending by a single bank, borrowing by firms could, for example, shift to other banks or non-banks who are unaffected by the regulatory requirement. However, in the case of system-wide macroprudential requirements, this is less straightforward.

3.1 Vector Auto Regression models and their conflation of two types of shock to capital

In common to this work, the current literature also uses Vector Auto Regression (VAR) models 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 perhaps fails to adequately disentangle shocks to banks' capital ratios consistent with a change in prudential requirements. 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 it out. 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 possible 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 & 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.[8] But such an ordering, 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.

This work therefore offers a new means of identifying a shock to capital that conforms with a given set of priors as to the direction of the effect shock to prudential requirements. By doing so, it attempts to offer a tighter identification than that offered by traditional VAR models.

4 The VAR-based methodology with sign restrictions used in this analysis

It is impossible to observe directly which changes in past bank capital ratios are caused by changes in regulation. This is the case not only due to the shortage of past changes in bank regulatory requirements, but also because it is difficult to disentangle the extent to which changes in bank capital are due to other developments (shocks to technology, bank profitability, creditworthiness, for example).

The methodology used here employs a VAR model of the joint dynamics of bank capital and a set of macro-financial variables; but attempts to identify past shocks to banks' capital ratios that – through their associated direction of movements in other variables – might proxy the nature of a shock to bank capital requirements, at least under certain assumptions. These 'sign restrictions' are of a spirit similar to those 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,

[8] 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).

that 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 its 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), Barnett and Thomas (2013)). But – to the best of the authors' knowledge – this methodology has yet to be used in the context proposed here: of identifying a shock to capital consistent with a change in regulatory requirements.

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.

Banks' choice is likely to depend on the relative cost of these three options, which in turn depends on the state of the economy and the structure of the financial system.[9] There is some evidence to suggest that banks' dividend payments are likely to be sticky,[10] 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 managers 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* (ie the Modigliani-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

[9] For further discussion, see Giese et al. (2013).

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

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.

In keeping with these priors, this methodology seeks to isolate shocks to capital ratios associated with a decrease in bank lending, and a worsening outlook for bank profitability. This reduction in future profitability should be specific to the banking sector distinguishing it from any sort of negative shock to the economy as a whole. It therefore seems natural to impose the restriction that this reduction in lending be accompanied by a reduction in bank equity prices, relative to that of the entirety of the UK equity market.

To attempt to isolate a credit supply shock driven by increased capital requirements, the additional restriction is imposed to identify increases in capital associated with an *increase* in the quantity of issuance of bonds by private non-financial corporates (PNFCs). This is motivated by how, in the face of a reduction in lending supplied by banks due to regulatory pressures, non-financial firms would be expected – at least in part – to substitute their demand of credit formally obtained from banks, to that in private bond markets (Kashyap, Stein and Wilcox (1993) develop this idea). The overall effect on GDP is left unrestricted.

Table 3: 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.

Together, these restrictions attempt to identify reductions in bank lending growth resulting from decreased bank loan supply that is consistent with a possible transmission mechanism for the effects of an increase in future macroprudential capital requirements during a credit boom. In such circumstances, non-financial corporates are assumed to demand an equal volume of credit, but – in the face of a reduction in credit supply by banks – obtain this through securities issuance instead. These restrictions, and a summary of their economic justification, are given in Table 3.

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 regulatory requirements. In doing so it is able to achieve a tighter identification of shocks than that possible using an assumption on the order in which a shock affects variables.

A detailed description of the method and its estimation is given in the Annex.

4.1 The assumptions underlying this identification approach

The strength of the approach based on sign restrictions is how it allows policy makers to identify past changes in bank capital that accord with their priors as to how future changes in macroprudential capital requirements will affect variables of interest. But it is not without caveats.

In particular, the assumed direction of response of other variables assumed here – ie. that an increase in capital requirements is associated with a reduction in lending – is only one possible set of priors as to the transmission mechanism of an aggregate increase in banks' regulatory capital requirements. And there are several caveats in using results based on past changes in bank capital/lending to gauge the impact of *future* changes in the macroprudential policy when such policy actions are not present in the past data.

First, the impact of changes in regulatory capital requirements may vary considerably depending on the macroeconomic environment. In particular, there may be conjunctural 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.

Second, the degree to which the Modigliani-Miller theorem fails to hold – ie. 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.

Thirdly, the approach is open to a considerable '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 the most 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 its greatest 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 (ie. 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 more muted than that given here.

In summary, this paper provides a useful top-down 'ready-reckoner' of the short-run effects of an increase in aggregate bank capital requirements, that 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.

4.2 Model selection

The VAR 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 (ie. 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. This choice of a single lag may seem surprising, given that economic intuition might suggest that the effect of a shock to bank capital on lending and growth would be propagated over a longer lag structure, and will therefore later be relaxed as a check on the robustness of the framework (see Section 5.2). However, the selection of a single lag by the two criteria may reflect the low degrees of freedom arising there being relatively few data observations, relative to the number of variables in the VAR.

5 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 7 and 8 show the impulse response functions for M4 lending and GDP growth. Full results are shown in Tables 4 and 5. 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 percentage points (far-right panel of Table 5). This is associated with a 0.25 percentage 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 $16/84^{th}$ 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 percentage 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 9 and 10 show the cumulative effect on the *levels* of M4 lending and GDP. The level of lending is reduced by approximately 1.4 per cent after around 17 quarters while GDP is cumulatively reduced by 0.25 per cent. Full results showing the impact on the levels of all variables are shown in Table 5.

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 11 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.[11] They are 'structural' in the sense that they represent the meaningful economic relationship the VAR is intended to find – that pertaining to shocks to

[11] 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 $y_t=B^{-1}Ay_{t-1}+u_t$.

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 12 – 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.

Charts 7-10: 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*).

Chart 7: M4 Lending growth

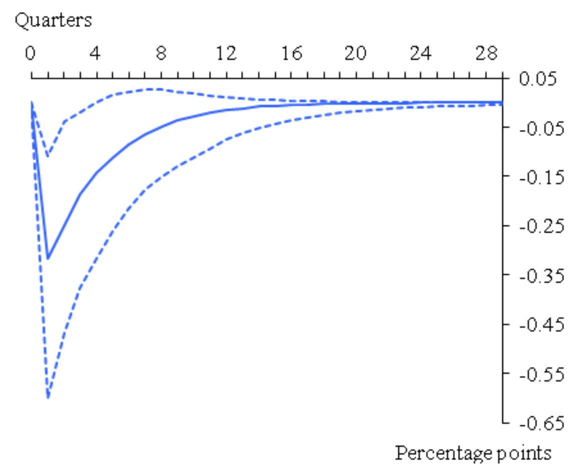


Chart 8: GDP growth

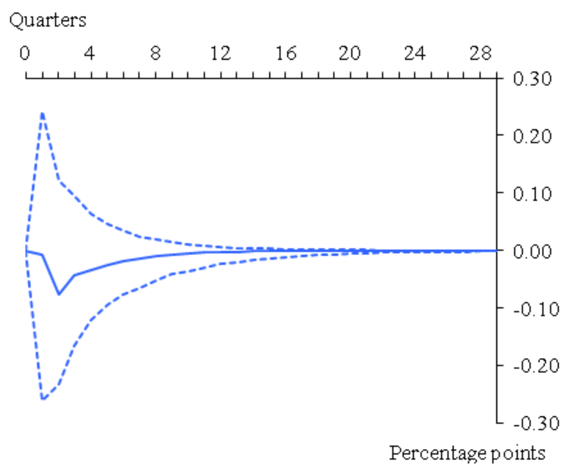


Chart 9: Level of M4 Lending

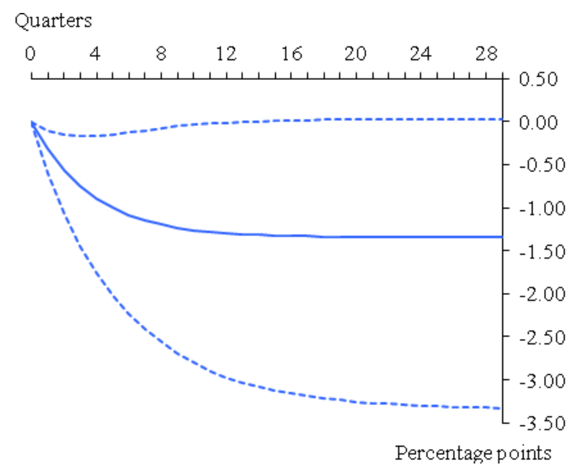
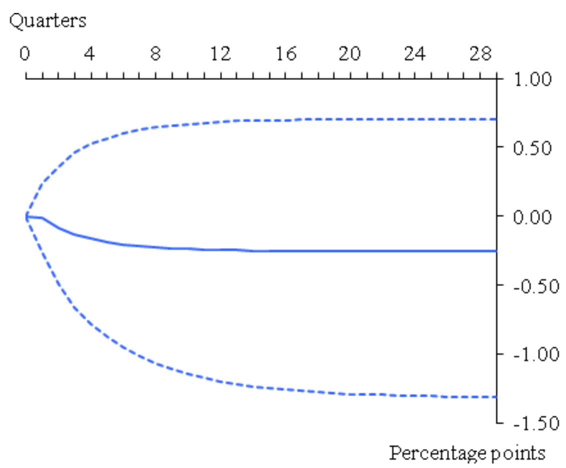


Chart 10: Level of GDP



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

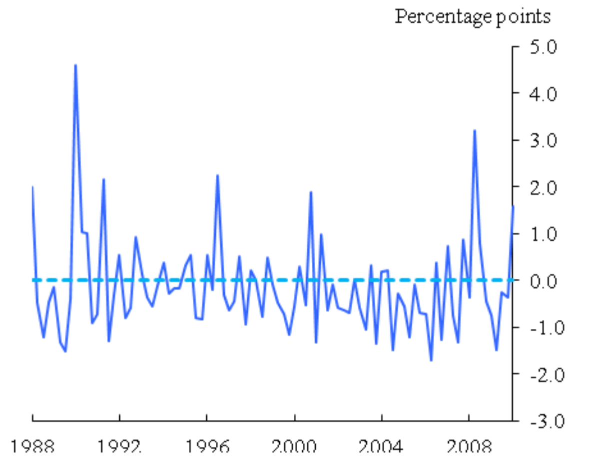
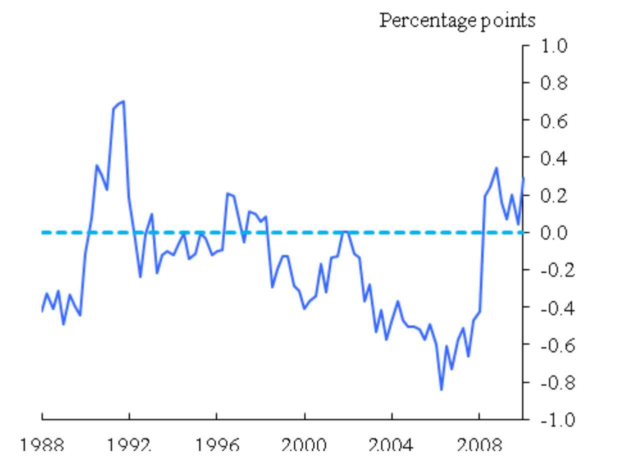
Chart 11: First-difference in capital ratios: historical shock series	**Chart 12:** First-difference in capital ratios: historical shock series (backward-looking eight-quarter moving average)
	

Table 4: 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.

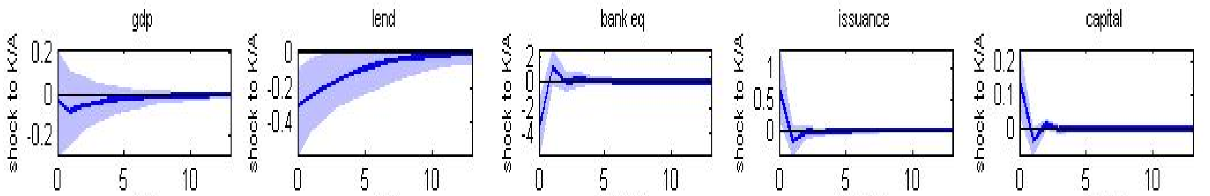
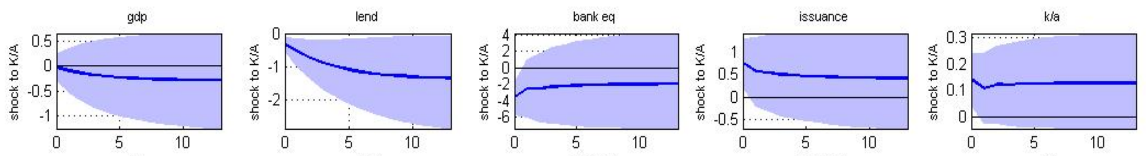


Table 5: Cumulative impact of a 15 basis point (one standard deviation**)** structural shock to the *change* in UK bank capital-to-asset ratios on the levels of other variables



In addition, Chart 12 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.

5.1 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 policy makers 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 six per cent). 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 13. Intuitively, an increase in macroprudential capital requirements during 2006-7 would have increased bank resilience and reduced the severity of the subsequent crisis.

Charts 15-18 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 16^{th} and 84^{th} percentile responses. The effect of this counterfactual increase in capital ratios is to reduce median quarterly lending growth by up to 1.5 percentage 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 percentage points greater than that actually witnessed. Whilst the direction of response given by the 16^{th} and 84^{th} percentiles is similar, the dynamic of the 84^{th} percentile is much closer to the observed series.

The overall effect on growth is less marked, with quarterly GDP growth reduced under the median response by up to 0.3 percentage points pre-crisis, and then increased by up to 0.6 percentage points since. And the 16^{th} and 84^{th} percentile outcomes between them encapsulate the opposite direction of response: the 84^{th} percentile response shows growth *increasing* by more than 0.5 percentage points before the crisis and reducing significantly at the end of the sample. The median counterfactual ratio of credit-to-GDP (Chart 14) is less than its actual outturn during 2006-9; but the resilience of lending means that it shows no decline since.

Charts 13-18: Counterfactual paths of M4 and growth, had banks' regulatory capital requirements been held at 6.1 percent from 2006:1

Solid lines show actual data; dotted lines show counterfactuals corresponding to the 50th, 16th and 84th percentile responses.

Chart 13: UK-operating bank capital ratio

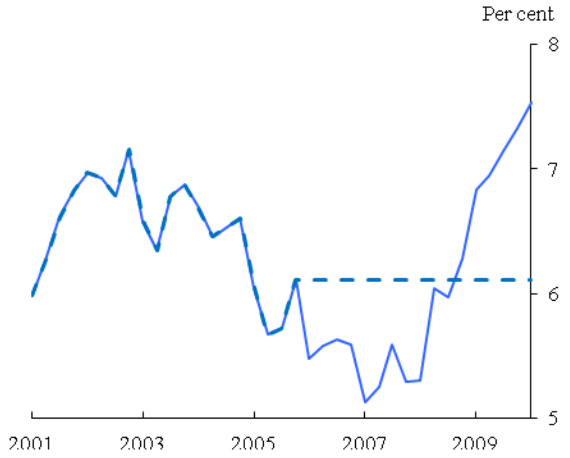


Chart 14: Credit:GDP ratio

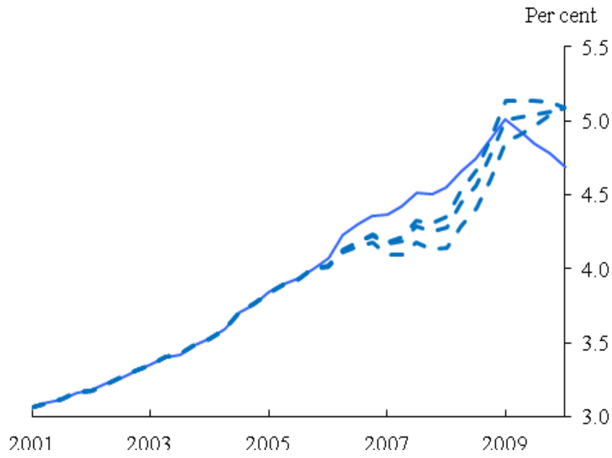


Chart 15: M4 lending growth

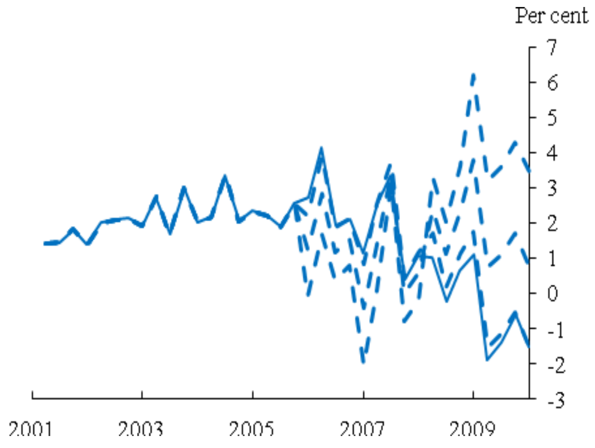


Chart 16: GDP growth

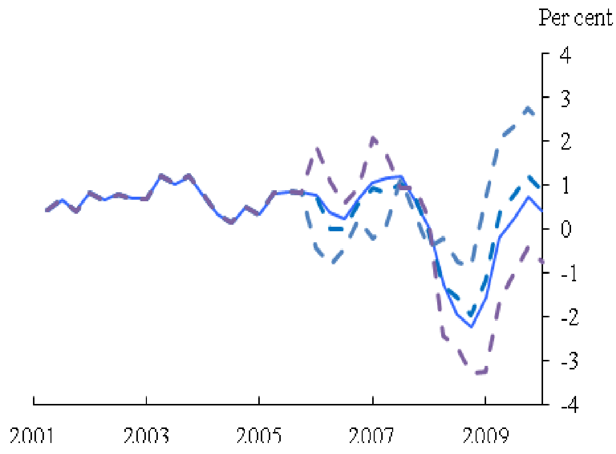


Chart 17: Level of M4 lending

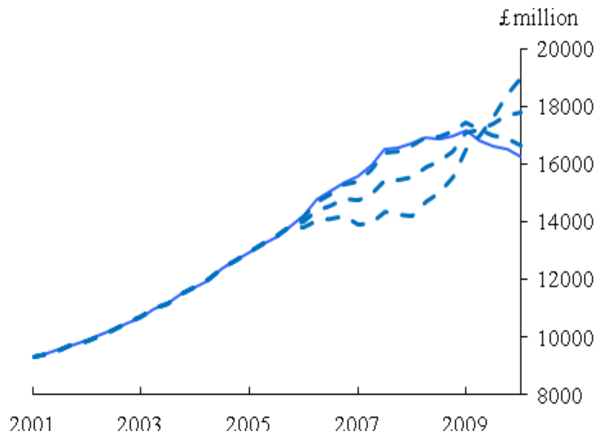
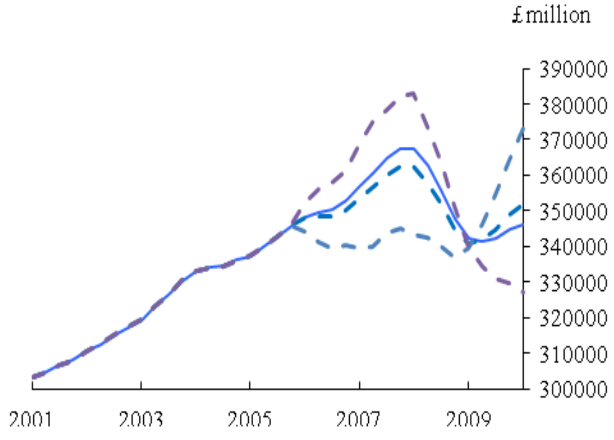


Chart 18: Level of GDP



Under the assumption that a macroprudential shock works in the way specified in Section 4, these results indicate that intervention by a macroprudential policy-maker that 'smoothed-through' declines and increases in aggregate bank capital ratios, can smooth the peaks and troughs in the lending and credit-to-GDP cycles.

5.2 Robustness check

Four 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 (Chart 1) 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.

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

Chart 19: Impulse response of M4 Lending growth to a 15 basis point shock to the *change* in UK bank capital-to-asset ratios

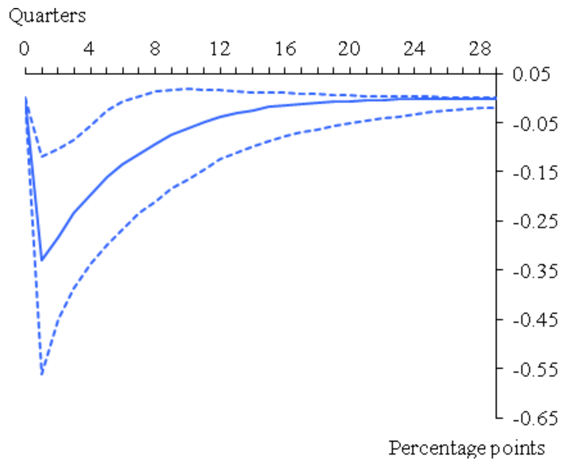
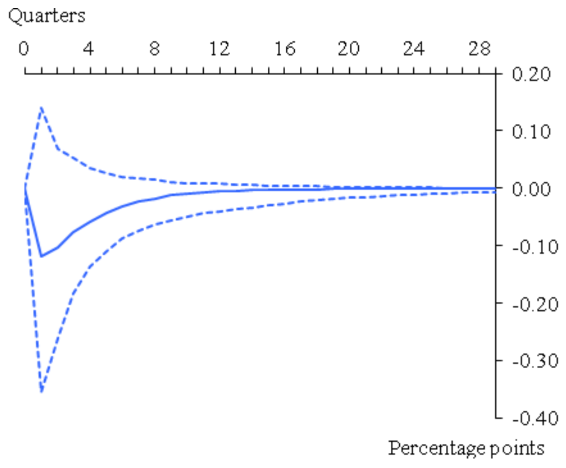


Chart 20: Impulse response of GDP growth to a 15 basis point shock to the *change* in UK bank capital-to-asset ratios



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

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 credit (see discussion in Section 4.1, and Uhlig (2005)).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 19 and 20).

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.

Third, given the correlation structure between bank lending, GDP and capital ratios seems to be greatest with more than one lag (see Chart 5 and 6) and the importance of the nexus between these factors, a model was also including two lags of each variable. Results are broadly similar to those above.

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 – ie. 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)).

5.3 *Comparison of these results to those elsewhere in the literature*

This section compares the magnitude of our results to those found elsewhere in the comparable literature. While, as explained in Section 3, median results of this analysis have no greater likelihood of occurring than any other based on a different percentile of the Median Target model, for improved readability Table 7 presents only the median results. For the sake of comparison, the penultimate row of the table converts the 15 basis point increase in capital ratios applied here to a 1 percentage point increase. The final row also gives the impact of a 1 percentage point increase in *risk weighted asset*s, assuming an average risk weight across UK banks' assets of 50 per cent.[12]

The median impact on lending and output resulting from our analysis, let alone that of the 84th percentile outcome, is larger than that found in other 'top down' studies based on aggregate bank capital data. Francis and Osborne (2009) and Cosimano and Hakura (2011) both find increases in regulatory capital to decrease lending. But a one percentage point increase in (risk weighted) capital ratios in their models achieves a reduction in lending volumes of 1.2/1.3% respectively, compared to 4.5% in our model. 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. At the same time, the analysis of the 16th percentile result of our model reduces lending by a maximum of 1.14%, a result similar to that estimated by Francis and Osborne (2009) and Cosimano and Hakura (2011).

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 one percentage point increase in risk weighted capital requirements to have a 0.77 percentage point initial reduction in secured 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 percentage point reduction in growth after five quarters. However, an equivalent shock to capital requirements on

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

lending to non-financial corporates produces a 4.0 percentage 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 in *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.

6 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 economy. One of the powers of the FPC is to direct a change in sectoral capital requirements.[13] 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 12). This approach takes the results of the VAR 'as given', assumes they represent a reasonable proxy of the shocks the

[13] See Bank of England (2013).

approach is seeking to capture (ie. 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.[14] That is:

$$Sectoral\_lending\_growth_t = \alpha * Sectoral\_lending\_growth_{t-1} + \beta * structural\_shock_t + \varepsilon_t$$

This is performed for the series of lending growth in each sector separately. Results are shown in Table 6, the rows of which show the regression coefficients corresponding to lending to each sector: households, private non-financial corporates (PNFCs), and 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.[15] 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.

Table 6: 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*)

[14] 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.
[15] 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.

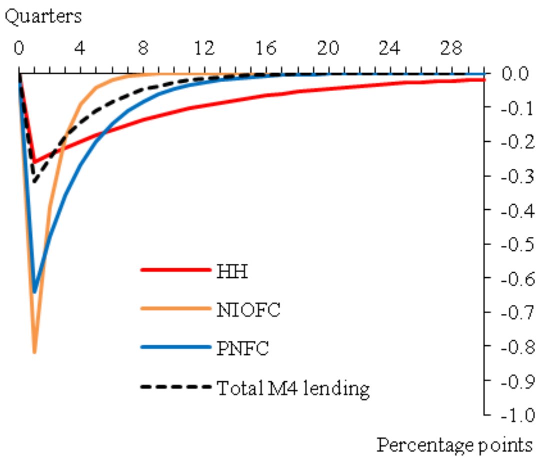
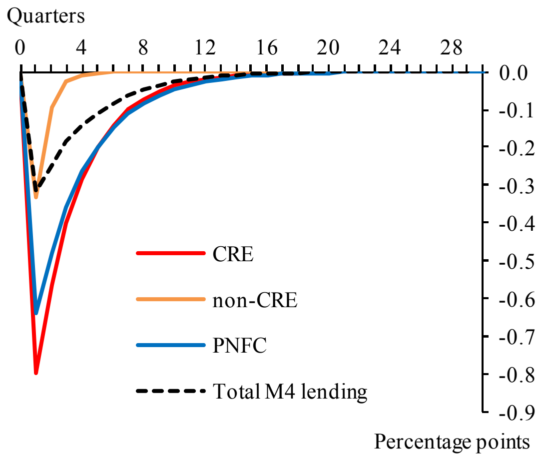
Chart 21: Impulse responses of a 15 basis point (one standard deviation) shock to the change in UK bank capital-to-asset ratios on growth of lending to different sectors	**Chart 22:** Impulse responses of a 15 basis point (one standard deviation) shock to the change in UK bank capital-to-asset ratios on growth of lending to CRE and non-CRE PNFCs
	

Chart 21 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 6). The effect of this shock over subsequent quarters – ie. 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 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.[16] 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 22 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.

7 Conclusion

This paper provides an estimate of the possible effect of future changes in aggregate regulatory capital requirements – such as those instigated by a mcroprudential 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 capital ratios of banks operating in the UK (unweighted for risk) is associated with a median reduction of around 1.4%

[16] 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).

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 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.

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, the work could 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.

Table 7: A comparison of the median result of this analysis to that found elsewhere in the literature				
	Nature/size of shock to capital	**Lending**	**GDP**	**Comparison** (where applicable)
Berrospide and Edge (2010)	15 percentage point increase in non-risk weighted capital ratio	0.5 percentage point *increase* in lending growth after two quarters	Insignificant response whose median peaks at a 0.2% increase in GDP growth after the shock	
Francis and Osborne (2009)	1 percentage point increase in risk-weighted capital requirements leading to a 65 basis point increase in the long-run capital ratio	1.2% reduction in long-run lending volume	N/A	Smaller long-run impact
Cosimano and Hakura (2011)	1.3 percentage point increase in non-risk weighted capital ratio	1.3% reduction in long-run lending volume.	N/A	Smaller long-run impact
Angelini et al (2011)	1 percentage point increase in risk-weighted capital requirements	N/A	0.09% decrease in long-run level	
BIS MAG (2010)	1 percentage point increase in risk-weighted capital requirements implemented over 8 years	N/A	0.03 percentage point reduction in annual growth	
Bridges *et al*.(2014)	1 percentage point (permanent) increase in risk-weighted capital requirements (leading to a 1 percentage point increase in risk-weighted capital ratio after around 12 quarters)	3.5 percentage point reduction in overall lending growth over three years 0.77 percentage point reduction in secured household loan growth after one quarter 0.19 percentage point reduction in unsecured household loan growth after five quarters 4.0 percentage point reduction in lending growth to CRE after one quarter 2.1 percentage point reduction in lending growth to non-CRE PNFCs after one quarter	N/A	Larger initial impact on overall lending growth.
BoE 2011 FSR	4-6 percentage point increase risk-weighted capital ratio		0.4-0.6% decline in long-run level	Smaller impact
This analysis (median modelled outcome)	15 basis point (cumulative) increase in non-risk weighted capital requirements	0.25 percentage point reduction in lending growth which fades to zero after 30 quarters 1.4% cumulative reduction in long-run level of lending	Effect insignificant (though median level is reduced by 0.25 per cent in the long run)	
	1 percentage point increase in non-risk weighted	1.7 percentage point reduction in lending growth; 9 percent cumulative reduction in long-run level of lending;	Effect insignificant (though median level is reduced by 1.7 per cent in the long run)	
	1 percentage point increase in risk weighted capital requirements	**0.85 percentage point reduction in growth; 4.5 per cent cumulative reduction in long-run level of lending**	**Effect insignificant (though median level is reduced by 0.85 per cent in long-run)**	

8 Annex

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

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

where $x(t)$ is a (n-by-1) vector of n endogenous variables; $x(t\text{-}1), \ldots , x(t\text{-}p)$ are vectors of lagged endogenous variables; B, $A(1), \ldots , A(p)$ 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}:

$$x(t) = C(0) + C(1)x(t\text{-}1) + C(p)x(t\text{-}p) + u(t)$$

where $C(0) = B^{-1}A(0)$ is a vector of constants; $C(1) = B^{-1}A(1), \ldots , C(p) = B^{-1}A(p)$ 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 3) 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 $\varphi^{(l)'}\varphi^{(l)}$.

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