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How does credit supply respond to monetary policy and bank minimum capital requirements? ☆

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ABSTRACT

We use data on UK banks' minimum capital requirements to study the interaction of monetary policy and capital requirement regulation. UK banks were subject to both time-varying capital requirements and changes in interest rate policy. Tightening of either capital requirements or monetary policy reduces the supply of lending. Lending by large banks reacts substantially to capital requirement changes, but not to monetary policy changes. Lending by small banks reacts to both. There is little evidence of interaction between these two policy instruments. The differences in the responses of small and large banks identify important distributional consequences within the financial system of these two policy instruments. Finally, our findings do not corroborate theoretical models that raise concerns about complex interactions between monetary policy and macro-prudential variation in capital requirements.

1. Introduction

By the middle of the 20th century, both academic economists and policy makers advocated the use of counter-cyclical monetary policy to stabilize the economy. Bank regulatory policies, such as capital requirements, cash reserve requirements, and other prudential tools, were focused instead on long-term microeconomic objectives, typically defined as individual banks' "safety and soundness". But following the recent global financial crisis, "macro-prudential" regulation—which seeks to preserve the resilience of the financial system as a whole, including by managing aggregate bank credit flows over the cycle and thereby reducing the risks that large cyclical movements pose to individual institutions—has increasingly been viewed as a desirable instrument of counter-cyclical policy. Changing banks' minimum capital requirements not only has the familiar aim of building up capital in good times to act as a loss-absorbing buffer in bad times, but also can have the goal of stabilizing the credit cycle itself, reducing credit growth when the economy overheats, and mitigating disruptive credit crunches when the economy suffers a downturn. This latter goal is appropriately "macro-prudential," since a shallower

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credit cycle should reduce the incidence of financial crises generated by imprudent lending and the mispricing of risk, thus enhancing the stability of the financial system.

Under Basel III, regulators have agreed to vary minimum capital requirements over time as part of the cyclical mandate of macro-prudential policies.[1] Anecdotal evidence from Colombia suggests that, during the 2007–2008 credit boom, macro-prudential policy was a more powerful instrument to manage aggregate credit than monetary policy.[2] But to our knowledge, no previous work[3] documents the relative effectiveness of these two tools for managing bank lending, or examines the extent to which the two tools magnify or lessen each other's impact. This paper aims to fill that gap by providing the first empirical examination of the independent effects and potential interactions of monetary and capital requirements policy on bank lending.

Our analysis is made possible by an apparently unique policy experiment performed in the UK during the 1990s and 2000s. As we explain more fully in Section 2, the Financial Services Authority (FSA) varied individual banks' minimum risk-based capital requirements substantially. The extent of this variation across banks in the minimum required risk-based capital ratio was large (the minimum required capital ratio was 8%, its standard deviation was 2.2%, and its maximum was 23%). The variation in the average capital requirement over the business cycle was also large, and tended to be counter-cyclical, as envisaged under Basel III.

In earlier studies, Aiyar et al. (2014a, 2014b, 2014c), showed that changes in minimum capital requirements had large effects on the supply of credit by UK banks that were subject to UK capital regulation during the sample period of 1998–2007. Apparently, equity finance was sufficiently costly for banks that increases in capital requirements imposed important constraints on the supply of bank credit. Due to the unique aspects of the UK database on regulated banks, those papers were able to identify moments of exogenous changes in capital requirements, and control for changes in loan demand (made possible by detailed information on the sectoral specialization of lenders), and thus, isolate the effects of changes in minimum capital requirements on *loan supply*. The focus of those papers was on bank loan-supply responses to capital requirement changes. This paper extends the findings of those earlier papers to model how loan supply responds to the combination of capital requirement changes and changes in monetary policy.

As elaborated further below, the theory of the bank lending channel of monetary policy (e.g., Bernanke and Gertler, 1995) predicts that contemporaneous changes in capital requirements should affect the transmission of monetary policy to loan supply.[4] Additionally, Thakor (1996) argues that the sign of this interaction between the two policies will depend on the change in the term premium associated with a given change in monetary policy. If the term premium increases (falls), government bonds become a more (less) attractive investment opportunity, given their zero risk weight relative to lending, leading banks to reallocate their portfolio towards (away) from government securities. A contemporaneous increase in the capital requirement should reinforce (weaken) this effect. These theories may have important implications for the coordination of monetary and macro-prudential policy. To our knowledge, ours is the first paper to test these theories and compare the effects of the two instruments on individual bank lending side by side.[5]

During our sample period, the FSA and the Bank of England were mutually independent organizations, with the former focused on individual bank regulation and supervision and the latter primarily responsible for price stability. Formally, Her Majesty's Treasury (HMT), The Bank of England and the FSA met as part of a tripartite group to discuss matters of financial stability. But to the best of our knowledge, UK monetary policy did not explicitly take into account capital requirements of individual banks. Similarly, while there was a memorandum of information sharing between the FSA and the Bank of England, the framework used by regulators (ARROW) does not explicitly mention monetary policy. This apparent lack of coordination among these two policy tools within this institutional setup provides an ideal framework to examine the individual and joint effects of these two independent policy instruments on loan supply.

[1] Basel III envisages a "counter-cyclical capital buffer" of up to 2.5% of risk-weighted assets, which would be subject to the principle of reciprocity. Thus, for example, if the UK raised system-wide minimum capital requirements by 2.5%, other regulators would also raise capital charges on the UK assets of banks under their jurisdiction by this amount (UK regulators could raise capital requirements by more than 2.5%, but the reciprocal increase by other jurisdictions would only apply up to the 2.5% ceiling). In addition to cyclical variation of minimum capital ratios, macro-prudential policy could entail other cyclical variation in policy instruments (e.g., liquidity and provisioning requirements) as well as "structural" interventions to promote financial stability. For more details, see Tucker (2009, 2011), Galati and Moessner (2011), Bank of England (2011), and Aikman et al., (2011).

[2] Indeed, in the case of Colombia, macro-prudential policy was used only after repeated efforts to reduce credit with increases in interest rates (which had resulted in a cumulative 400 basis point increase in the policy rate) had failed to achieve the desired objective during the credit boom in 2007 (Uribe, 2008).

[3] The few other relevant studies that examine the impact of capital requirements on credit conditions include BCBS (2010) and MAG (2010) who focus on the effect on lending spreads and Nadauld and Sherlund (2009) who study the impact on sub-prime credit. See Bank of England (2011) for a survey of the existing evidence.

[4] In theory, the interaction effect is not the result of policy coordination, but rather reflects the economic consequences of independently implemented policy changes in capital requirements and monetary policy, as we discuss more fully in Section 2.

[5] Most previous work on the question of interaction focuses on the welfare consequences of macro-prudential and monetary policy in DSGE modeling frameworks, and posits important interactions between macro-prudential and monetary policies. For example Angelini et al. (2014) find that coordination among monetary and macro-prudential policy is beneficial if financial and housing market shocks dominate the economy. Similarly, Beau et al., (2011) find that monetary policy can be more effective in reaching its goals if it takes into account the effects of macro-prudential policy on the economy. But the conclusions of these early studies are mainly hypothetical, as they rely on calibration without empirical evidence regarding the actual interaction between monetary and macro-prudential policies. See also Dell'Ariccia et al. (2010), Angelini et al. (2012), Gelain and Ilbas (2013), International Monetary Fund (2012, 2013). Interestingly, Gelain and Ilbas (2013) argue that coordination of monetary policy and capital policy may not be desirable, particularly if the main objective of the latter is to safeguard financial stability.

Our paper also investigates the extent to which the responses of bank loan supply to changes in monetary policy and capital requirements vary by type of bank. There is a large literature documenting that the effect of monetary policy on loan supply – measured either by the quantity of lending or by credit spreads on bank loans – depends on bank characteristics related to the cost of finance, particularly bank size (Kashyap and Stein, 1995, 2000; Ehrmann et al., 2003; Jimenez et al., 2008; Dell'Ariccia et al., 2013). Owing to the unique policy environment of the UK, we are able to investigate the differential effects of changes in both capital requirements and monetary policy on the loan supply responses of different types of banks.

Our results suggest that changes in monetary policy and banks' capital requirements have substantial and independent effects on loan supply. Consistent with previous work (e.g., Kashyap and Stein, 2000), we find that the amount of lending by large banks does not react as much as the lending of small banks to changes in monetary policy. In a concentrated banking system like that of the UK, this implies that monetary policy faces limitations in influencing aggregate bank loan supply. Changes in capital requirements, on the other hand, have large effects on the loan supply of large and small banks alike. Finally, contrary to existing theoretical perspectives on the interaction of monetary policy and capital requirement changes, we are unable to identify interaction effects between changes in monetary policy and capital requirements.

In Section 2, we discuss the relevant economic theory that underpins the transmission to loan supply of changes in capital requirements, changes in monetary policy, and their interaction. Section 3 briefly describes the bank-specific UK data base that we employ to measure changes in capital requirements and changes in loan supply and loan demand. Section 4 describes the regression framework in greater detail. Section 5 presents the results. Section 6 discusses questions of robustness and endogeneity. Section 7 concludes.

2. Theory

In this section we discuss the theory relevant for our empirical tests, starting first with the relevant transmission channels of monetary policy, then capital requirements, and finally theories about how they might interact.

Monetary policy (a change in the interest rate controlled by the central bank) may affect bank lending via several channels. The bank lending channel of monetary policy predicts a loan contraction following an interest rate increase, so long as cash reserve requirements are binding and banks are liquidity constrained (Bernanke and Gertler, 1995). The bank capital requirement channel of monetary policy, presented in Van den Heuvel (2002), predicts that bank capital may fall following a monetary policy contraction as a result of unexpected losses due to interest rate risk. In that case, unless dividends are cut, loans will have to shrink to restore the targeted capital buffer. Finally, recent work emphasizes shifts in the risk-taking preferences of banks as a channel through which monetary policy can affect bank lending. Low interest rates can increase banks' net worth (Adrian and Shin, 2010), reduce asset volatility and thereby reduce perceptions of risk (Borio and Zhu, 2008), and make nominal target returns harder to achieve (Rajan, 2005).[6] This may lead to an increase in banks' appetite for risk, and therefore, riskier lending. Empirical evidence for the bank lending, bank capital and risk-taking channel of monetary policy is provided in Kashyap and Stein (1995, 2000); Gambacorta and Mistrulli (2004) and Altunbas et al. (2010), respectively.

Changes in capital requirements affect bank lending, so long as equity is costly and capital buffers are binding. Both of these conditions have been shown to hold empirically for our UK sample (see Aiyar et al. (2014a), Bridges et al. (2014), and Francis and Osborne (2009)).

The standard story about the bank lending channel of monetary policy implies potentially important interactions between monetary policy changes and changes in capital requirements; both policy instruments affect lending through related contingencies involving bank balance sheets. The bank lending channel of monetary policy relies on the cost to banks of raising debt other than deposits – that is, debts that are not directly affected by reserve requirements – when reserve requirements are binding and banks are constrained in the amount of non-depository debt they can raise (Bernanke and Gertler, 1995). An increase in a binding minimum capital requirement, and the implied limit on leverage, will, therefore, reduce the ability of a bank to access non-depository debt, and thus should strengthen the impact of monetary policy on lending.[7]

Alternative mechanisms for an interaction effect can be posited via a "time-varying risk-aversion" channel. For example, assume that low policy rates are associated with greater bank willingness to undertake risk, as supported by a substantial body of empirical evidence (De Nicolo and Lucchetta, 2010; Jimenez et al., 2008; Ioannidou et al., 2015). In a low interest rate environment, banks become less risk averse, which implies that they may be willing to allow their capital buffers – defined as the proportion of capital relative to risk-weighted assets that the bank maintains in excess of its minimum capital ratio requirement – to fall by more in response to an increase in minimum capital requirements. If capital buffers shrink in a low interest rate environment, then a rise in capital requirements will have a smaller effect in shrinking credit supply that it would have during a time of higher interest rates.

[6] See Dell'Ariccia et al. (2010) for a review

[7] Francis and Osborne (2009) and Aiyar et al. (2014a) show that minimum capital ratio requirements tend to be binding constraints on bank lending in our sample, which is, of course, a necessary condition for changes in minimum capital ratio requirements to affect lending. A binding capital ratio, however, does not imply that the capital ratio is equal to the minimum requirement, since banks will desire to maintain a positive capital buffer to ensure that they remain in compliance.

Table 1
Variables and data sources.

Variable	Definition	Source (Bank of England Reporting Form)	Notes
ΔCapReq – change in banking book capital requirement ratio	FSA-set minimum ratio for capital-to-risk weighted assets (RWA) for the banking book. Also known as "Trigger ratio".	BSD3	
Lending	Bank lending to non-financial sectors of the economy	AL	We construct lending by summing the stock of items AL1–AL14 in the AL form
ΔBankrate	Change in the Bank of England main policy rate	Bank of England website	
Inflation	Log change in the GDP deflator	Office of National Statistics	
Real GDP Growth	Log change in real GDP	Office of National Statistics	
SIZE	Dummy variable = 1 when the time average of relative size is in the top 15% of the distribution	BT	Relative size is defined as a banks total lending in terms of total banking system lending
Liq	Dummy variable = 1 when the time average of the ratio of liquid to total assets is in the top 15% of the distribution	BT	Liquid assets are defined as the sum of BT21 (Cash), BT23 (Financial Market Loans) and BT32 (Investments), divided by assets.

For further information on the BT and AL form, please see:
http://www.bankofengland.co.uk/statistics/Pages/reporters/defs/default.aspx

Table 2
Summary statistics.

Variable	Units	Mean	SD	Min	Max	Obs
Capital requirement ratio	%	10.8	2.26	8	23	2630
Change in capital requirement ratio	Basis points	−1.4	29.7	−500	500	2524
Lending to real economy	£000s	9483	28,510	0	274,140	2630
Change in lending to real economy	%	0.8	16.5	−98.3	85.3	2503

Thakor (1996) proposes a formal theory of the interaction between monetary and capital requirements policy, based on banks' portfolio reallocation decisions following a change in either policy instrument. In his model, when capital requirements rise, competition and screening costs prevent banks from passing on the increased cost to borrowers. The relative decline in expected profits from lending relative to holding government securities, which have a risk-weight of zero, leads banks to reallocate their portfolio from the former to the latter. The extent to which a capital requirement change interacts with monetary policy in this framework depends on the coinciding change in the interest rate term premium. If long rates rise (fall) by more than short rates, implying a positive (negative) term premium, government securities will become more (less) profitable. This will magnify (reduce) the effect of the rise in capital requirements. On the contrary, if the capital requirement declines, a positive (negative) term premium will reduce (increase) the effect of the change in the capital requirement on lending. In other words, this theory predicts that changes in capital requirements and monetary policy both affect banks portfolio choice between government securities and loans, but the sign of the interaction term depends on the change in the term spread.

To summarize: the literature on the credit supply response of monetary policy and bank minimum capital requirements is growing rapidly, in line with the perceived policy importance of the issue. But empirical work—especially on the impact of capital requirements on loan supply—remains scant.[8] The theoretical literature posits several distinct channels through which monetary policy and capital requirements could interact, with different implications for the sign and magnitude of the potential interaction between the two instruments. Ultimately the nature of the interaction between instruments, if any, needs to be resolved empirically.

[8] International Monetary Fund (2012) constructs a country panel study using aggregate data to measure the effects of monetary policy and capital requirements policy, as well as other macro-prudential policy measures. The study finds statistically significant effects of capital requirements on credit growth, and finds that this effect is stronger during credit busts. The authors do not find any significant interaction effects between monetary policy and macro-prudential policy (footnote 18). Such data, however, have various limitations, including various challenges of measurement, the non-comparability of policy instruments and enforcement of prudential regulation of capital across countries, as well as the problem of endogeneity of capital requirements and monetary policy and potential differences in endogeneity of those policy processes across countries.

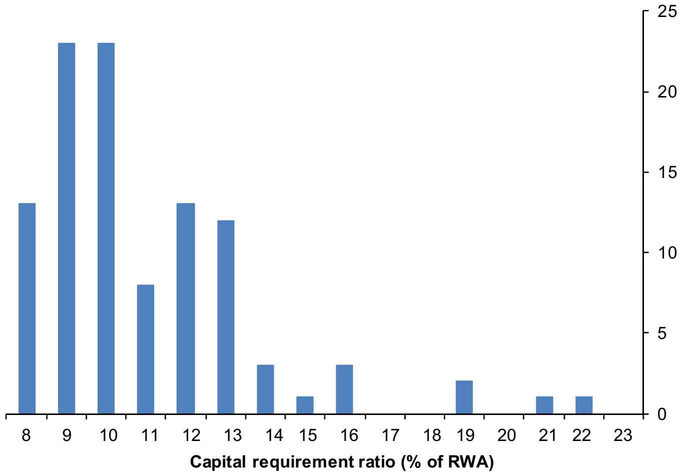

Fig. 1. Histogram of minimum capital requirement ratio.

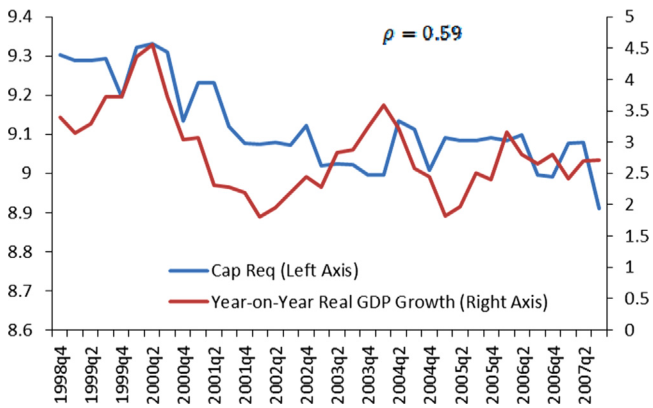

Fig. 2. Cap Req vs real GDP growth over time.

3. UK capital regulation 1998–2007

Our empirical analysis is made possible by a regulatory policy regime that set bank-specific, time-varying capital requirements. These minimum capital requirement ratios were set for all banks under the jurisdiction of the FSA – that is, all UK-owned banks and resident foreign subsidiaries. Foreign branches' capital requirements are set by regulators in their countries of origin. Our sample of UK-owned and resident foreign subsidiaries accounted for 88 percent of bank lending in the UK on average during our sample period. Bank capital requirements are not public information. We collect quarterly data on capital requirements, and other bank characteristics, from the regulatory databases of the Bank of England and FSA. Our sample comprises 88 regulated banks (48 UK-owned banks and 40 foreign subsidiaries). Bank mergers are dealt with by creating a synthetic merged data series for the entire period (e.g., if two banks merge in 1999, they are treated as merged in 1998 as well). The variables included in this study are listed and defined in Table 1, and Table 2 reports summary statistics.[9]

Discretionary policy played a greater role in the UK's setting of minimum bank capital ratios than in the capital regulation of other countries. A key focus of regulation was the so-called "trigger ratio": a minimum capital ratio set for each bank that would trigger regulatory intervention if breached. For more details on how which trigger ratios were set, and the consequences for banks of that variation, see Francis and Osborne (2009) and Aiyar et al. (2014a).

As Table 2 and Fig. 1 show, the variation in minimum capital requirements as a share of risk-weighted assets over the sample period was large. The mean capital requirement ratio was 10.8%, the standard deviation 2.26, the minimum value 8%, and the maximum value 23%. As Fig. 2 shows, changes in capital ratio requirements varied significantly over the business cycle, too. More detailed information about the distribution of changes in capital requirements, divided according to the size

[9] The data used in this study exclude outliers based on the following criteria: (1) trivially small banks (with total loans less than £3,000,000 on average), or (2) observations for which the absolute value of the log difference of lending in one quarter exceeded 1.

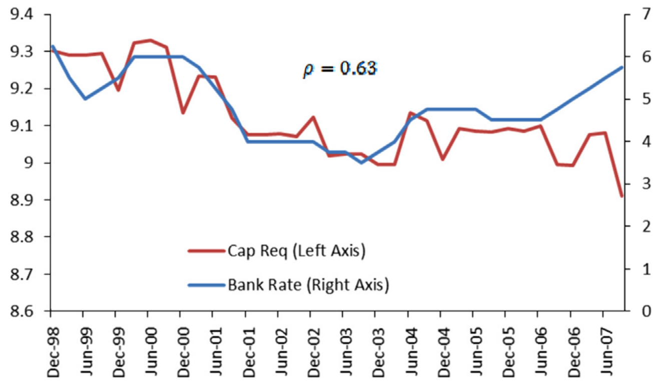

Fig. 3. Cap Req vs Bank Rate over time.

and frequency of the changes in bank minimum capital requirements, as well as additional information regarding the cyclical pattern of capital requirement changes and their cross-section correlates, can be found in Aiyar et al. (2014a).

Average non-weighted capital requirement ratios ranged from a minimum of 10.2% in 2007 to a maximum of 11.2% in 2003. This is striking counter-cyclical variation given that the sample period was one of varying positive growth, but no actual recessions (by way of comparison, the Basel III counter-cyclical buffer is supposed to vary between 0 and 2.5% over the entire business cycle inclusive of recessions).[10] Thus, although the FSA lacked any explicit macro-prudential mandate over the period, the outcome of its bank-specific decisions was in fact counter-cyclical in nature.

Aiyar et al. (2014a) consider the extent to which capital requirements were binding on bank behavior, based on the co-movements between weighted capital ratios and weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements that they maintain. For all four groups of banks, the variation in minimum capital requirements was associated with substantial co-movement in actual capital ratios, confirming the conclusions of Alfon et al (2005), Francis and Osborne (2009), and Bridges et al. (2014) that capital ratio requirements were binding on banks' choices of capital ratios for UK banks during this sample period.

4. The effects of capital requirement and monetary policy changes on bank lending

In this section, we estimate the effects of changes in monetary policy and capital requirements on bank lending. Our measure of bank lending is loans to the domestic non-financial sector and is constructed from the Bank of England's AL form.[11]

The change in the stance of monetary policy is measured as the change in the key instrument of monetary policy, Bank Rate. Fig. 3 shows the variation in Bank Rate over our sample period. Of course, Bank Rate is endogenous with respect to other macroeconomic variables. For example, if central banks follow some form of Taylor Rule, they adjust their policy rate in reaction to levels of inflation (relative to its long-term target) and output growth. Thus, in regressions that seek to identify the effects of monetary policy on bank lending (e.g., Kashyap and Stein, 1995, 2000; Ehrmann et al., 2003, Gambacorta and Mistrulli, 2004) researchers control for the effects of other variables, such as GDP growth and inflation, which may be correlated with monetary policy.

Changes in capital requirements should affect lending by a regulated bank only when bank equity is relatively expensive to raise, and when regulatory requirements are binding constraints (see Aiyar et al. (2014a)).[12] We confine our sample to UK-regulated banks and measure their lending responses to both economy-wide monetary policy and bank-specific capital requirements.[13] Following the logic of Kashyap and Stein (1995, 2000), Ehrmann et al. (2003) and Gambacorta and Mistrulli (2004) we include bank characteristics as interaction effects in our regression analysis. In so doing, we allow the effects of monetary policy and changes in capital ratio requirements to affect bank lending differentially depending on bank characteristics.

Bank lending may vary due to changes in loan demand. To identify loan-supply responses to capital requirement changes, we control for loan-demand changes. Following Aiyar (2011), and Aiyar et al. (2014a), the basic strategy is to exploit sector level lending by bank i to 14 different sectors in conjunction with employment growth for each of these sectors at time t. Our bank-specific, time-varying measure of loan demand is $z_{it}=\sum_q s_{iqt}\Delta z_{qt}$, where s_{iqt} denotes the share of sector q in

[10] Within this framework, national authorities can choose to raise the counter-cyclical capital buffer above 2.5%, but international reciprocity is voluntary beyond that point.

[11] http://www.bankofengland.co.uk/statistics/Pages/reporters/defs/default.aspx

[12] As we noted before, a binding minimum capital requirement is not synonymous with banks having zero buffers. Banks will generally target a positive buffer above the regulatory minimum.

[13] As discussed in Aiyar et al. (2014a), branches of foreign banks operated in the UK, but were not subject to UK capital requirements. Thus, our sample includes only UK-based banks and subsidiaries of foreign-based banks operating in the UK, which were subject to UK capital requirements.

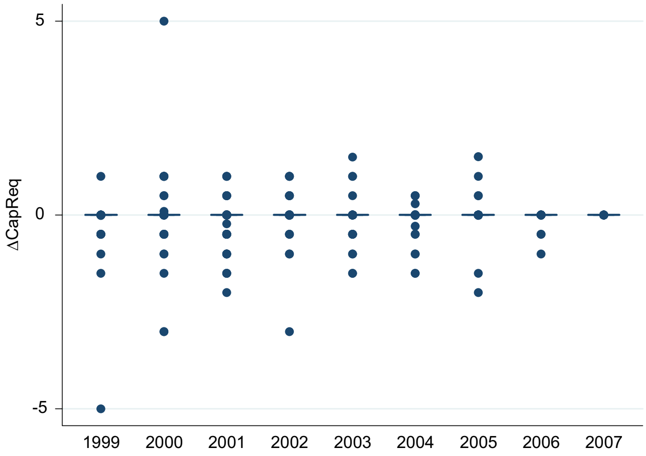

Fig. 4. Box plot of ΔCapReq.

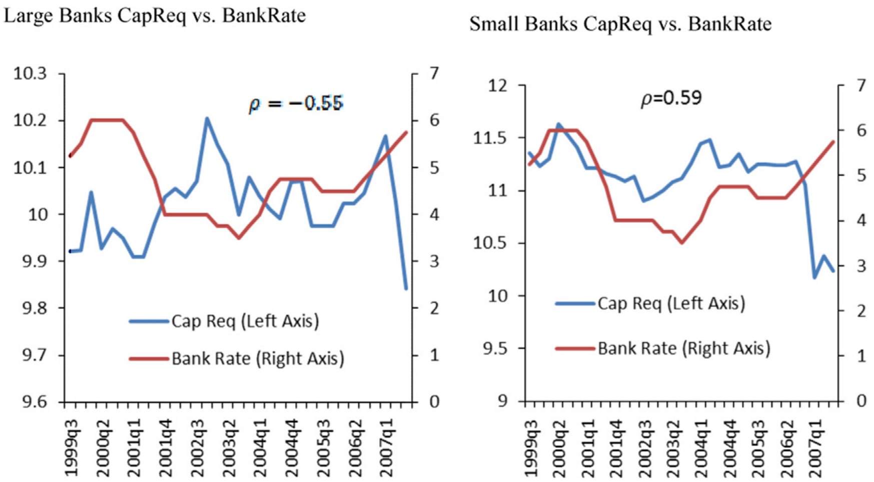

Fig. 5. CapReq vs BankRate by sizev. *Source*: Bank of England and Author's calculations. Note: 'CapReq' is the simple average of capital requirement ratios across large banks. ρ is the correlation coefficient between the Bank rate and CapReq between 1998q3 and 2006q4.

bank i's lending portfolio in period t. Δz_{qt} is the growth rate of real activity in sector q, which we define as the quarter t on $t-6$ quarter employment growth rate, expressed at quarterly frequency.[14]

Our empirical model follows previous work that tries to assess the effects of monetary policy on bank lending growth with individual bank balance sheet data. In this approach, lending growth is typically regressed on changes in monetary policy and several macroeconomic control variables. This body of work has also found that certain bank characteristics affect the transmission of monetary policy to bank lending. In particular, Kashyap and Stein (1995) find that, as a result of informational asymmetries, smaller banks find it more difficult to raise non-depository debt in times of monetary tightening and their lending growth therefore responds to a greater degree. In follow-up work, Kashyap and Stein (2000) also find that banks with a greater stock of liquidity tend to react less to an equivalent change in monetary policy (see also Campello (2002), and the discussions in Peek and Rosengren (1995a, 1995b, 1997, 2000) of differential adjustment of banks to shocks to capital). In our analysis of loan-supply responses, we explore interactions of bank size categories with both changes in capital requirements and changes in monetary policy. Ceteris paribus we expect small banks to have higher costs of raising equity (greater asymmetric information problems), implying larger loan-supply responses to capital requirement changes for small and large banks. We also expect small banks to have greater loan-supply responses to monetary policy changes, reflecting their greater costs of issuing market debt as a substitute for deposits. Fig. 4 displays the changes in capital requirements over time and by bank size. Fig. 5 shows the changes over time in capital requirements aggregated for each of the two bank size sub-groups.

[14] It is not only the level of growth in real activity, but also the persistence that matters, for banks to increase lending growth to a particular sector. Because employment growth is volatile, we therefore use the t on $t-6$ quarter employment growth rate as a proxy for the expansion in real activity in that sector. We note that all of our results are robust to expressing demand as either a year-on-year growth rate, or omitting measures of demand entirely. Note also that in this case, expressing the growth at quarterly frequency effectively means dividing the six-quarter growth rate by 6.

Following the theoretical literature reviewed in Section 2, in their study of the monetary policy transmission mechanism with bank level data across European countries, Ehrmann et al. (2003) present an empirical model in which capital and liquidity ratios, as well as the size of a bank, may enter interactively with monetary policy. Their simple theoretical model also suggests the inclusion of inflation and real GDP growth in the modeling of the loan-supply effects of monetary policy. Following their simplest baseline model (before considering bank-specific interaction effects), and adding changes in minimum capital requirements as well as our measure of changes in loan demand, we arrive at the following baseline panel regression specification:

$$\Delta \log(L_{i,t}) = \alpha_i + \sum_{j=0}^{L} a_j \Delta \mathrm{CapReq}_{i,t-j} + \sum_{j=0}^{L} b_j \Delta r_{t-j} + \sum_{j=0}^{L} c_j \Delta \log(\mathrm{GDP})_{t-j} + \sum_{j=0}^{L} d_j \Delta \log(\mathrm{GDPDEF})_{t-j} + \sum_{j=0}^{L} e_j \Delta \mathrm{LoanDem}_{i,t-j} + \epsilon_{i,t} \quad (1)$$

Here α_i is a bank-specific fixed effect, r_t is the nominal bank rate, and $L_{i,t}$ is the stock of real lending to the real economy (deflated using the GDP deflator). ΔCapReq denotes the change in the banking book capital requirement ratio; $\Delta\log(\mathrm{GDP})_{t-j}$ the real GDP growth rate, and $\Delta\log(\mathrm{GDPDEF})_{t-j}$ is inflation measured by the GDP deflator.[15] $\Delta\mathrm{LoanDem}_{i,t-j}$ is the previously defined measure of bank-specific changes in loan demand.

Both the contemporaneous change in capital requirements and three quarterly lags are included in the equation.[16] As noted by Francis and Osborne (2009), on the basis of regulatory data we only observe a change in the capital requirement when the trigger ratio in a particular report differs from the trigger ratio in the preceding report from three months earlier; we do not know when, within that three month period, the change in capital requirements was introduced. Moreover, it is possible that FSA regulators—who maintain an ongoing dialog with the banks they supervise—might inform a bank in advance of a forthcoming change in the capital requirement ratio. Both these considerations indicate the necessity for a contemporaneous term of the dependant variable in addition to lags.

In addition to the above baseline specification, we also consider interaction effects. Banks respond to policy shocks differentially depending on their access to alternative sources of funding (high costs of alternative sources of finance should increase banks' responses to both monetary policy shocks and changes in minimum capital requirements). Previous research has also included banks' cash asset ratios and capital buffers (capital ratios in excess of capital ratio requirements) as measures of "financial slack" that could mitigate the effects of policy shocks on loan supply.[17]

In our specifications, we allow for all of these possible influences except capital buffers. As shown in Francis and Osbourne (2009) and Aiyar et al. (2014a), cross-sectional variation in capital buffers is not a measure of financial slack, but rather captures long-term cross-sectional differences in targeted buffers, which likely reflect different risk preferences and different costs of accessing finance. A similar argument can be made for liquid asset holdings (as noted in Kashyap and Stein (2000)), and indeed, there is substantial evidence that firms with higher costs of finance endogenously target higher long-term liquidity (e.g., Calomiris et al., 1995, Almeida et al., 2004). Nevertheless, Kashyap and Stein (2000) find in their sample of U.S. banks that liquid assets do seem to measure financial slack. Thus, in addition to bank size (which proxies for the cost of finance from non-depository sources) we include the liquid asset ratio as a bank characteristic in our model.

Finally, in order to investigate possible interactions between changes in monetary policy and minimum capital requirement ratios, we include an interaction term between the two policy instruments. This interaction term is also allowed to vary with bank-specific size and liquidity.

$$\begin{aligned}\Delta \log(L_{i,t}) = {} & \alpha_i + \sum_{j=0}^{L} a_j \Delta \mathrm{CapReq}_{i,t-j} + \sum_{j=0}^{L} b_j \Delta r_{t-j} + \sum_{j=0}^{L} c_j \Delta \log(\mathrm{GDP})_{t-j} \\ & + \sum_{j=0}^{L} d_j \Delta \log(\mathrm{GDP\_Def})_{t-j} + \sum_{j=0}^{L} e_j \Delta \mathrm{LoanDem}_{i,t-j} + \sum_{j=0}^{L} f_j \Delta r_{t-j} \Delta \mathrm{CapReq}_{i,t-j} \\ & + \sum_{j=0}^{L} g_j \mathrm{x}_{i,t-j} \Delta \mathrm{CapReq}_{i,t-j} + \sum_{j=0}^{L} h_j \mathrm{x}_{i,t-j} \Delta r_{t-j} \\ & + \sum_{j=0}^{L} m_j \mathrm{x}_{i,t-j} \Delta \log(\mathrm{GDP})_{t-j} + \sum_{j=0}^{L} q_j \mathrm{x}_{i,t-j} \Delta r_{t-j} \Delta \mathrm{CapReq}_{i,t-j} + \epsilon_{i,t} \end{aligned} \quad (2)$$

[15] Some previous studies (e.g.Gambacorta and Mistrulli, 2004) use CPI, rather than the GDP deflator, as their preferred measure of inflation. The Bank of England's inflation target was switched from RPIX to CPI in December 2003 making it difficult to use consumer price inflation indices to identify monetary policy in this equation. It is for this reason that we use the GDP deflator instead.

[16] Here we follow Aiyar et al. (2014a, 2014b, 2014c) in using a three-quarter lag structure. As those studies noted, adding an additional lag does not change the results but reduces the sample size and hence the precision of estimates.

[17] When we include either size or liquidity as an interaction effect they are measured as the indicator variables SIZE and Liq, as defined in Table 1.

In this specification, output growth, the change in Bank Rate, and the change in the capital requirement ratio, as well as the interaction between Bank Rate and the capital requirement ratio, are interacted with the vector $x_{i,t-j}$, which captures bank-specific attributes (balance sheet size and proportion of liquid assets). Inflation is not interacted with the other bank characteristics, a modeling choice that follows previous work by Kashyap and Stein (1995) and Gambacorta and Mistrulli (2004). We estimate various versions of this model. Some versions of the model employ a subset of the regressors presented in Eq. (2).

Specification (2) is well suited to test for interactions between changes in monetary policy and minimum capital requirements as predicted by the bank lending channel of monetary policy. But the theory developed in Thakor (1996) suggests that minimum capital requirements interact with changes in monetary policy through induced changes in the term premium. Eq. (3) below seeks to test that proposition:

$$
\begin{aligned}
\Delta \log(L_{i,t}) = {} & \alpha_i + \sum_{j=0}^{L} a_j \Delta \mathrm{CapReq}_{i,t-j} + \sum_{j=0}^{L} b_j \Delta r_{t-j} + \sum_{j=0}^{L} c_j \Delta \log(\mathrm{GDP})_{t-j} \\
& + \sum_{j=0}^{L} d_j \Delta \log(\mathrm{GDP\_Def})_{t-j} + \sum_{j=0}^{L} e_j \Delta \mathrm{LoanDem}_{i,t-j} + \sum_{j=0}^{L} f_j \Delta r_{t-j} \Delta \mathrm{term}_{t-j} \Delta \mathrm{CapReq}_{i,t-j} \\
& + \sum_{j=0}^{L} g_j \mathrm{x}_{i,t-j} \Delta \mathrm{CapReq}_{i,t-j} + \sum_{j=0}^{L} h_j \mathrm{x}_{i,t-j} \Delta r_{t-j} \\
& + \sum_{j=0}^{L} m_j \mathrm{x}_{i,t-j} \Delta \log(\mathrm{GDP})_{t-j} + \sum_{j=0}^{L} q_j \mathrm{x}_{i,t-j} \Delta r_{t-j} \Delta \mathrm{term}_{t-j} \Delta \mathrm{CapReq}_{i,t-j} + \epsilon_{i,t}
\end{aligned}
\tag{3}
$$

The difference between specifications (2) and (3) is that the "double" interaction terms between capital requirements and monetary policy have been replaced with "triple" interaction terms between capital requirements, monetary policy and the term premium. We define the term premium as the difference between the three-year yield[18] on UK gilts and Bank Rate.[19] This difference reflects the alternative predictions of the bank lending channel and Thakor's (1996) theory of monetary transmission.

5. Results

Table 3 reports various versions of the loan-supply regressions based on Eqs. (1) and (2), both with and without some control variables and some bank-specific interactions. All specifications are estimated in a panel fixed-effects framework, where the bank-specific fixed effect should capture heterogeneity in lending growth arising from relatively long-run, time-invariant bank characteristics.[20] The first column of the table does not include any macroeconomic controls. The second column introduces both real GDP growth and GDP deflator inflation as controls. The third column additionally interacts monetary policy and capital requirement ratio changes with each other, while the fourth, fifth, and sixth columns add an increasing number of interaction terms relating to bank characteristics. All the coefficients reported here are the sum of the contemporaneous impact and three lags. We choose to include three lags because this number of lags maximizes the *F*-test statistic for our specification.[21] We report in parentheses beneath each coefficient the *F*-statistics for the joint test that the sum of the contemporaneous and lagged effects of each variable is statistically significantly different from 0.

In Table 3, we find that lending growth responds negatively to increases in capital requirements, regardless of the chosen specification. The estimated effects are large; given that the mean capital requirement ratio in our sample is 10.8%, a coefficient of -0.05 implies an elasticity of supply with respect to capital requirement changes of roughly 0.55. Once we control for GDP deflator inflation and real GDP growth, the change in Bank Rate also has a statistically significant negative effect on lending growth, regardless of specification. Column (5) in Table 3 shows that bank size interactions are important. Both the change in Bank Rate and GDP growth interact with bank size. Bank size is measured here using an indicator variable that distinguishes the top 15% of the UK's largest banks from other banks (i.e., SIZE=1 if the bank is in the large size

[18] The results are very similar if we use the 10-year yield instead.

[19] We tried several variants of this specification. First, we *added* the 'triple interaction' terms to specification (2), rather than replacing the double interaction terms. Second, we replaced the term spread with a dummy variable taking the value of one when the term spread is positive and 0 otherwise. Finally, we replaced the change in Bank Rate with the term spread that is predicted by a regression of Bank Rate on the term spread. All of these specifications yielded very similar results and are available upon request.

[20] A fixed effects specification is preferred to random effects because we have no strong prior that the bank-specific effect is not correlated with other explanatory variables—as required by random effects. Post-estimation Hausman tests reject the null of a random effects specification.

[21] In Appendix B, Table B1, we show that including a lagged endogenous variable does not affect our estimates, although we do not include this in our reported results in Tables 3–8 because of the potential bias that arises from including lags of the dependent variable in our panel regressions. Table B2 of Appendix B reports various regressions which include different numbers of lags of capital requirements, as well as a plot of the *F*-test statistics for each of those specifications, which shows that the specification using three lags has the highest *F*-test statistic.

Table 3
Estimates of Model (1) and (2) – lending.

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.078***	−0.073***	−0.057**	−0.048**	−0.067**	−0.056**
(Prob > *F*)	0.00169	0.0036	0.0165	0.0300	0.019	0.033
ΔBankrate	−0.0132	−0.05**	−0.048**	−0.054***	−0.06**	−0.071***
(Prob > *F*)	0.446	0.0159	0.0211	0.00951	0.0174	0.00548
Inflation		0.0199	0.0216	0.0203	0.0213	0.0199
		0.419	0.385	0.409	0.390	0.417
Real GDP growth		0.078*	0.078*	0.068*	0.098**	0.087*
		0.062	0.062	0.09	0.044	0.077
ΔLoanDem	0.025**	0.029**	0.029**	0.028**	0.028**	0.027**
	0.0392	0.0190	0.02	0.023	0.018	0.019
ΔCapReq*ΔBankrate			0.115	0.0855	0.0959	0.0528
			0.170	0.375	0.349	0.687
ΔBankrate*Liq				0.0665		0.0839
				0.272		0.179
GDP growth*Liq				0.130		0.111
				0.343		0.427
ΔCapReq*Liq				−0.0861		−0.0770
				0.812		0.832
ΔCapReq*ΔBankrate*Liq				0.119		0.153
				0.791		0.738
ΔCapReq*SIZE					0.0545	0.0429
					0.227	0.329
ΔBankrate*SIZE					0.04*	0.05**
					0.0956	0.0319
GDP growth*SIZE					−0.07*	−0.06*
					0.053	0.094
ΔCapReq*ΔBankrate*SIZE					−0.0118	0.0311
					0.917	0.824
Constant	0.00134	−0.0681	−0.0682	−0.0709	−0.0682	−0.0704
	(0.00960)	(0.0478)	(0.0478)	(0.0474)	(0.0475)	(0.0472)
Observations	1815	1815	1815	1815	1815	1815
R-squared	0.024	0.031	0.036	0.045	0.039	0.048
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq and ΔBankrate are the quarterly changes in the banking book capital requirement and Bank Rate, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

grouping).[22] The coefficient on the interaction of size and the change in bank rate is statistically significant and positive, which indicates that large banks display less of a contraction in loan supply than smaller banks with respect to a tightening of monetary policy. This is consistent with the finding of Kashyap and Stein (1995) that large banks contract their lending to a lesser degree in response to a tightening of monetary policy. In our sample, large banks exhibit a much smaller loan-supply responsiveness to monetary policy (columns (5) and (6)), while the effect of bank minimum capital requirements does not differ to a statistically significant degree between large and small banks.[23] Our results regarding the interaction of GDP growth and bank size indicate that pro-cyclicality in loan supply is an exclusively small-bank phenomenon. As in the case of our results regarding the different effect of monetary policy on the loan supply of large banks, it appears that large banks' superior access to non-depository debt markets enables them to insulate their cost of funding loans from a variety of domestic macroeconomic shocks.[24]

The coefficient on the interaction of the change in Bank Rate and the change in the capital requirement is never statistically significantly different from 0. This suggests that, while both instruments have independent effects on lending, the

[22] If instead one models the effect of bank size using a continuous measure of size (the log of assets), the interaction terms that include size are not significant. This reflects the fact that size is bimodal (there are small banks and large banks, not a continuum of categories); behavioral differences associated with size are not well captured by a model that constrains size to enter linearly.

[23] Although the coefficients on the variable ΔBankrate and the interaction term ΔBankrate*SIZE are slightly different from each other in magnitude, their sum is not significantly different from zero. This is the case in Table 3 and all subsequent tables providing regression results.

[24] We also experimented with including additional regressors as controls, which are not reported here. We tried various bank-specific, time-varying characteristics such as the proportion of core deposit funding and asset liquidity, and the inclusion of these variables did not affect our estimates for the key variables relating to capital requirement and monetary policy changes.

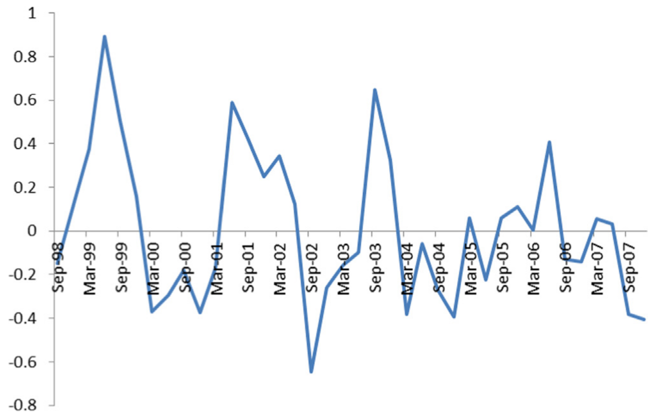

Fig. 6. Change in term premium.

effect of monetary policy is not amplified/dampened significantly by simultaneous changes in banking book capital requirements, as might be expected under the several different hypotheses described in Section 2.

Under the Thakor (1996) model, the lack of a significant interaction term between monetary policy and minimum capital requirement changes may arise from a failure to control for changes in the term spread, which have been both positive and negative during the sample period (Fig. 6). Table 4 reports estimates of Eq. (3). The results are very similar to those presented in the previous table. Size matters for the effect of monetary policy, but not the effect of minimum capital requirements, on bank lending; and changes in minimum capital requirements and monetary policy have an independent effect on bank lending. The interaction between the change in Bank Rate, the change in the term premium, and the change in capital requirements is never statistically significant. Allowing this "triple interaction" term to vary by bank characteristics makes no difference to the result.[25] In other words, we cannot confirm the theory of contingent interactions between monetary policy and capital requirements presented in Thakor (1996).

The fact that large banks do not react to changes in monetary policy has an important implication for an economy with a highly concentrated banking system like the UK. Based on our definition of size, large banks provide 94% of lending to the real economy in the UK, which implies that, unlike minimum capital requirements, monetary policy apparently was not a very powerful tool for managing bank lending in the UK during this time period. Of course, monetary policy may still affect lending growth via loan demand or other more interest-sensitive sources of credit supply.

6. Endogeneity

One of the main identification assumptions in models (1), (2) and (3) is that the change in minimum capital requirements is exogenous with respect to bank lending growth. It is unclear whether that assumption is justified. The estimates presented in Tables 3 and 4 could be subject to both reverse causality and omitted variable bias. In this section we present institutional and statistical evidence to demonstrate that these biases are likely to be small.

6.1. *Reverse causality*

Aiyar et al. (2014a) describe the institutional rules governing FSA regulation during this time in detail, which we briefly summarize below. The FSA's approach to supervision was implemented via ARROW (Advanced Risk Responsive Operating frameWork). In his review of UK financial regulation following the global financial crisis, Lord Turner, Chairman of the FSA, noted that regulatory decisions focused more on organization structures, systems and reporting procedures, than on credit risk factors (Turner, 2009). Similarly, the inquiry into the failure of the British bank Northern Rock revealed that ARROW did not require supervisors to engage in financial analysis, defined as information on the institution's asset growth relative to its peers, its profit growth, its cost to income ratio, its net interest margin, or its reliance on wholesale funding and securitization (FSA, 2008). This approach to bank regulation suggests that bank-specific lending growth or loan quality were not the main determinants of FSA regulatory decisions about capital requirements, an assertion that is further verified with a panel VAR analysis, discussed below.

To further assess whether reverse-causality is likely to be a serious problem we estimate three panel VAR models, which combine bank lending growth and loan quality information (write offs of loan losses) with the change in capital requirements. The three alternative versions of the Panel VARs that we consider include two two-dimensional Panel VARs that

[25] As noted in Section 4, we also experimented with several different variants of the specifications presented here, but the basic results remain the same.

Table 4
Estimates of Model (3) – Lending.

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.078***	−0.073***	−0.058*	−0.05*	−0.06*	−0.057*
	0.002	0.004	0.0604	0.0772	0.0628	0.0847
ΔBankrate	−0.013	−0.05**	−0.05**	−0.056***	−0.06**	−0.074***
	0.446	0.0159	0.0151	0.0073	0.013	0.005
Inflation		0.0199	0.0213	0.0206	0.0204	0.0196
		0.419	0.390	0.401	0.414	0.428
Real GDP growth		0.078*	0.078*	0.068*	0.097**	0.085*
		0.062	0.06	0.094	0.046	0.08
ΔLoanDem	0.025**	0.029**	0.03**	0.028**	0.027**	0.027**
	0.0392	0.0190	0.021	0.022	0.018	0.02
ΔCapReq*ΔBankrate *ΔTerm			0.0862	−0.272	−0.321	−0.0318
			0.715	0.923	0.820	0.927
ΔBankrate*Liq				0.0645		0.0832
				0.304		0.198
GDP growth*Liq				0.127		0.109
				0.351		0.430
ΔCapReq*Liq				−0.124		−0.115
				0.702		0.723
ΔCapReq*ΔBankrate *ΔTerm*Liq				0.399		0.462
				0.737		0.702
ΔCapReq* SIZE					0.0461	0.0370
					0.410	0.509
ΔBankrate*SIZE					0.0425*	0.0525**
					0.0835	0.0348
GDP growth *SIZE					−0.0706	−0.0604
					0.0508	0.0962
ΔCapReq*ΔBankrate *ΔTerm *SIZE					0.370	−0.0264
					0.717	0.945
Constant	0.00134	−0.0681	−0.069	−0.0718	−0.0675	−0.0693
	(0.00960)	(0.0478)	(0.048)	(0.0470)	(0.0478)	(0.0471)
Observations	1815	1815	1815	1815	1815	1815
R-squared	0.024	0.031	0.036	0.046	0.039	0.049
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq, ΔBankrate and ΔTerm are the quarterly changes in the banking book capital requirement, Bank Rate and the term premium, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

model the dynamic connections between capital requirement changes with either loan growth or loan quality, and a three-dimensional Panel VAR that models the dynamic interactions among all three variables. Consider first the two-dimensional panel VAR model of loan growth and capital requirement changes:

$$Y_{i,t} = \sum_{j=1}^{3} B_j Y_{i,\,t-j} + e_{i,\,t} \quad e_{i,t} \sim N(0,\ \Sigma)$$

where $Y_{i,t}$ contains $\Delta \text{CapReq}_{i,\,t}$ and $\Delta \log(L_{i,\,t})$. Both variables are expressed as deviations from their unit-specific mean, which is equivalent to removing the bank specific fixed effect. $e_{i,t}$ is a vector of reduced-form error terms which are jointly normally distributed with a mean of zero and the variance-covariance matrix Σ. To understand the effect of a change in capital requirements, further assumptions need to be made. To identify a change in capital requirements shocks, we assume that the change in capital requirements reacts to real lending growth with a lag. This is a realistic assumption, as regulators typically only observe real lending growth with a lag. In addition, the procedures necessary to change an institution's capital requirement imply that regulators can only react with a delay, even if they are able to observe real lending growth contemporaneously.

Our other two Panel VAR models are similar to the Panel VAR model of capital requirements changes and loan growth. In the two-dimensional Panel VAR model of loan writeoffs and capital requirement changes we assume as before that capital requirements can only respond to loan writeoffs with a lag. This is a potentially controversial assumption because non-

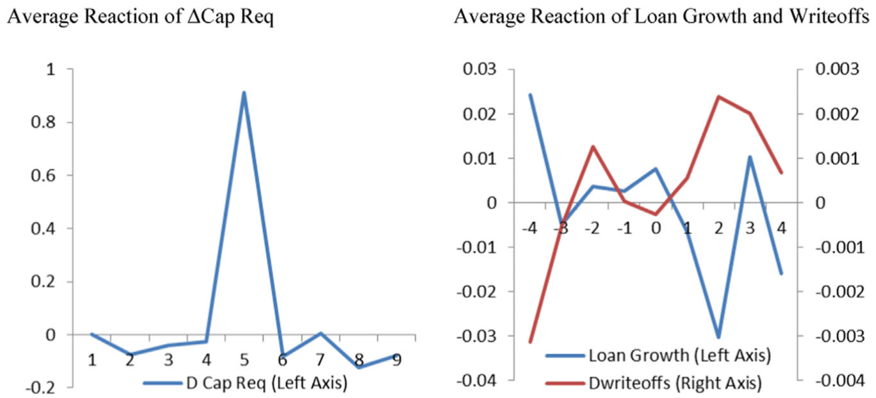

Fig. 7. Event analysis for ΔCapReq Rise.

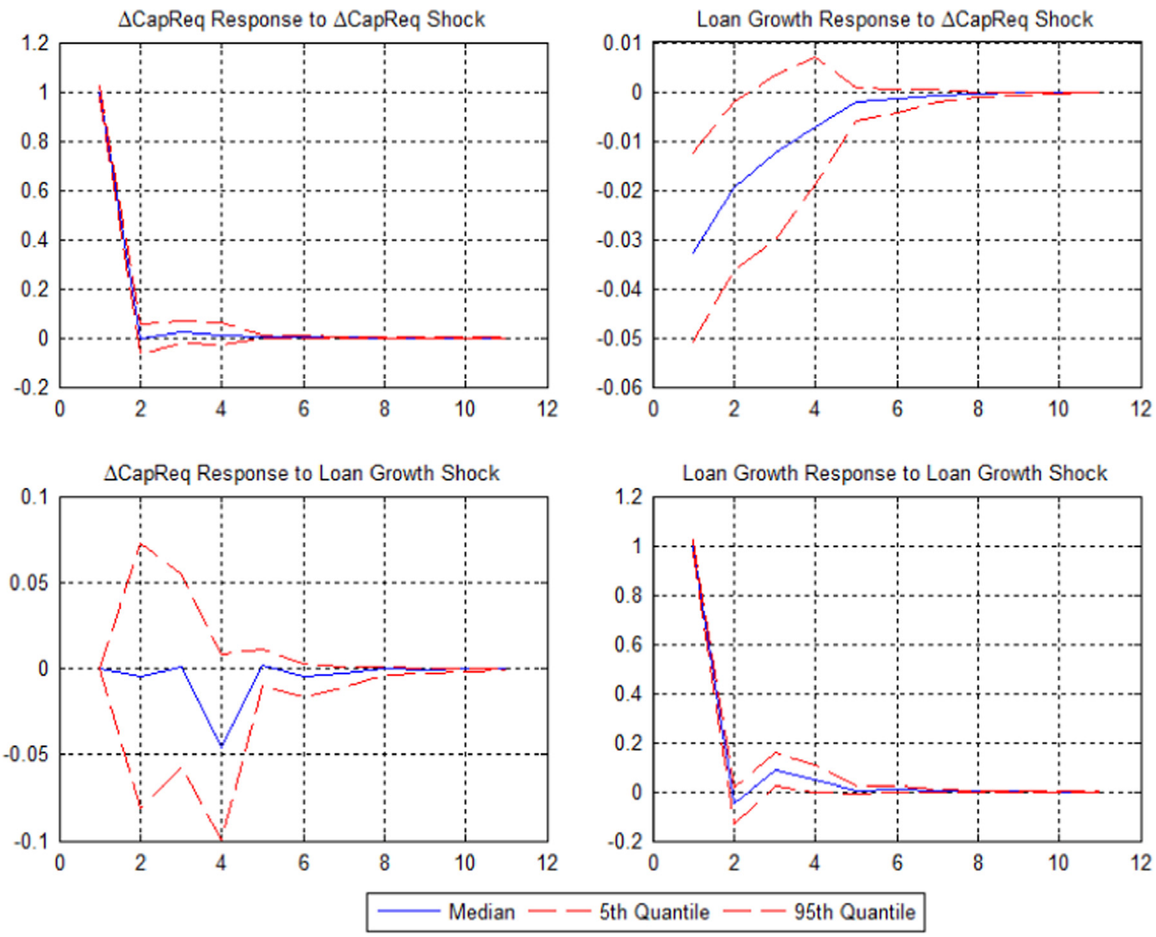

Fig. 8. Panel VAR I. Note: Figure shows median impulse responses from a panel VAR, identified with a choleski ordering where DCapReq is ordered before loan growth, together with the 90% coverage bands. The panel VAR model was estimated with the procedures described in Love and Zichinno (2006).

performing loans (which are not available in our data base) may be observed by regulators and may predict loan writeoffs. Thus, it is conceivable that our Panel VAR ordering should put writeoffs rather than capital requirement changes first in the ordering. As shown in Fig. 7, however, there is very little contemporaneous association between capital requirement changes and writeoffs, and therefore, it matters little which ordering is chosen. Fig. 7 reports what we label an “event

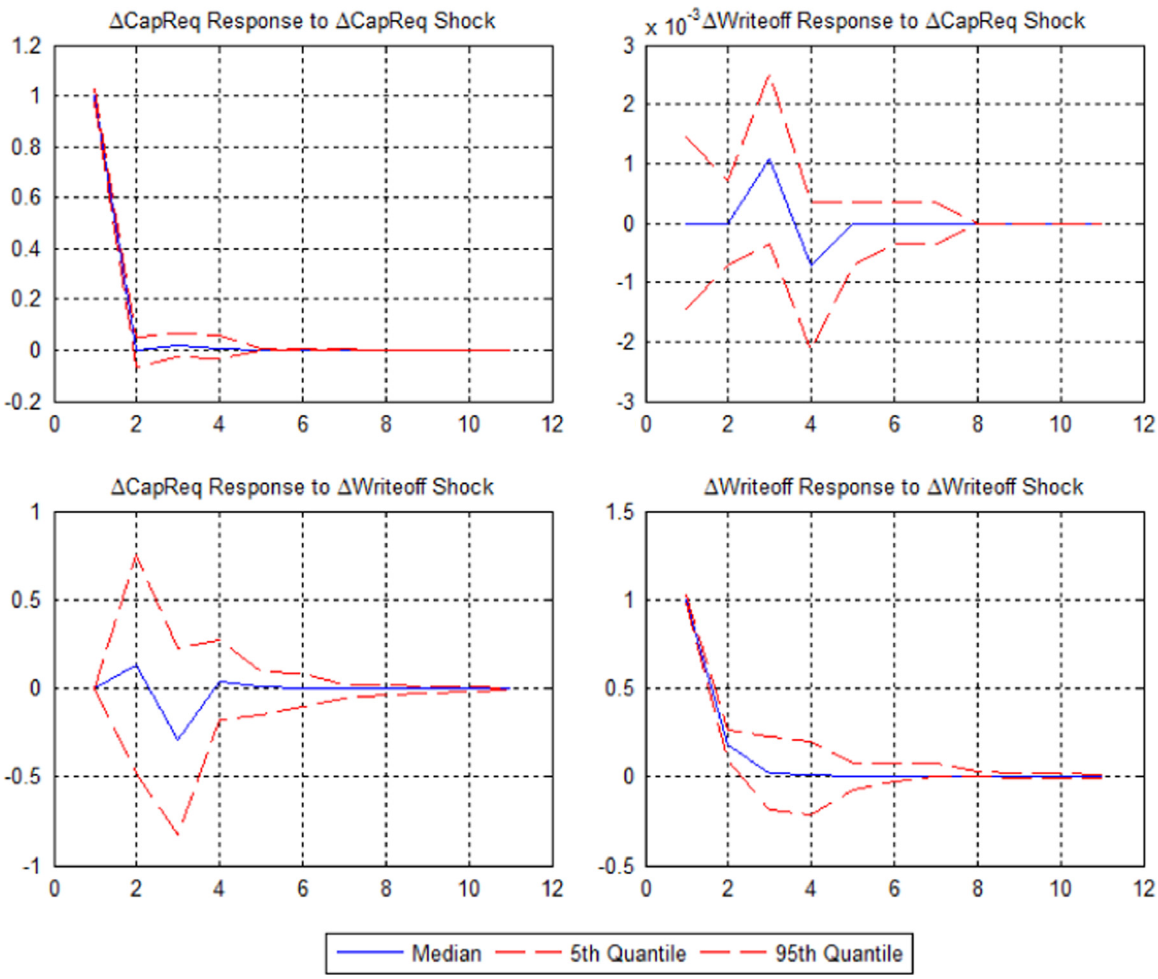

Fig. 9. Panel VAR II. Note: Figure shows median impulse responses from a panel VAR, identified with a choleski ordering where DCapReq is ordered before changes in the writeoff to total asset ratio together with the 90% coverage bands. The panel VAR model was estimated with the procedures described in Love and Zichinno (2006).

analysis" of capital requirement changes. This simply summarizes the data for the three variables of interest (capital requirements, loan growth and loan writeoffs) around the dates of capital requirement changes.

In the two-dimensional Panel VAR we put capital requirements ahead of writeoffs in the ordering, but in the three-dimensional Panel VAR we place writeoffs ahead of capital requirement changes. The results are unaffected by this decision. In all cases, as reported in Figs. 8 through 10, we find no evidence that capital requirement changes respond to shocks originating in loan growth or loan quality.

In general, impulse responses obtained from the Panel VAR models and the sum of coefficients from Model (1) will be different.[26] The sum of the impulse responses will be identical to the sum of coefficients over the same horizon if and only if the following four conditions are jointly satisfied: i) $\Delta\log(L_{i,t})$ is not autoregressive; ii) $\Delta\log(L_{i,t})$ does not granger cause $\Delta CapReq_{i,t}$; iii) $\Delta CapReq_{i,t}$ is not autoregressive, and iv) the impact coefficient of the change in capital requirements on lending growth in Model (1) is identical to the unbiased impact coefficient in the VAR. In the appendix, we formally show that these conditions are jointly sufficient to rule out endogeneity bias.

The panel VAR models are estimated using the approach proposed in Love and Zicchino (2006) to avoid bias arising from the interaction of lagged dependent variables and fixed effects in panel data. For each of the Panel VAR models, shown in Figs. 8–10, we plot the impulse responses to a 100 basis points change in capital requirements shock and the associated 5th and 95th posterior coverage bands based on the 500 Monte Carlo simulations. The numerical impact on real lending upon impact and for the first three periods is shown in Table 10. This table shows that the growth rate in real lending to the economy falls by about 3.3% upon impact and declines back to zero fairly rapidly. The final column of Table 10 shows

[26] See Bagliano and Favero (1998) for an elaboration of this point in the context of monetary policy.

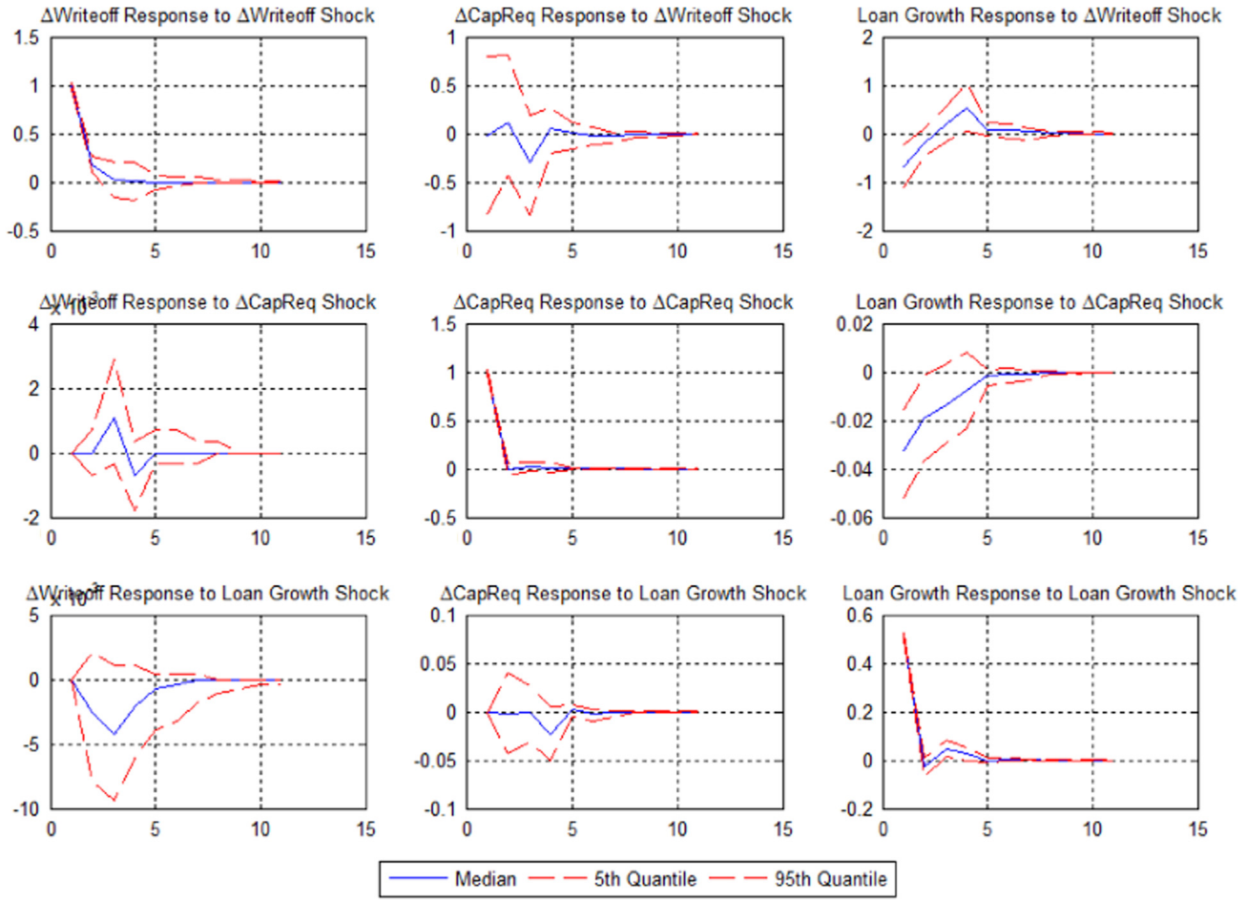

Fig. 10. Panel VAR III. Note: Figure shows median impulse responses from a panel VAR, identified with a choleski ordering where Changes in the writeoff to total asset ratio is ordered first, followed by DCapReq and loan growth is ordered last, together with the 90% coverage bands. The panel VAR model was estimated with the procedures described in Love and Zichinno (2006).

individual coefficients from a regression where, other than bank fixed effects, the only included variables are the contemporaneous change in the capital requirement, together with three lags. This specification has an estimated impact response of -3.73, very similar to, and not statistically different from, the corresponding panel VAR figures. Cumulating the real lending growth impulse response up to 4 quarters yields a median value of 7.3–7.2.This is almost identical to, and not statistically significantly different from, the sum of coefficients of 6.9 for the single equation specification in the ultimate column of Table 10. The similarity of the coefficients allows us to conclude that the joint conditions (i) through (iv) above are satisfied, which enables us to rule out any significant reverse causality from bank lending growth to changes in minimum capital requirements. This can also be seen more directly from another impulse response shown in Fig. 8, where we assess the impact of a shock to real lending growth on the change in the capital requirement. The effect of a 100 basis point increase in lending growth is not significantly different from 0. We can therefore reject the view that Granger-causality runs from real lending growth to the change in capital requirements.

To summarize, we estimate Panel VAR models that are less restrictive than Model (1), both in the dynamics of the variables, as well as, *conditional* on the correct identification scheme, with respect to the exogeneity assumption regarding the changes in the capital requirements variable. The similarity of the estimates from this approach to the single-equation approach suggests that the restrictions necessary for Model (1) to provide an unbiased estimate of the effect of the change in capital requirements on lending growth are not rejected by the data (see Tables 9 and 10).

6.2. Omitted variable bias

Even absent reverse causality, underlying changes to the quality of the bank's loan portfolio could be driving both regulatory changes in minimum capital requirements and changes in credit supply, thereby generating a spurious correlation between the latter two variables. To address this potential problem we examine the contemporaneous correlation between a proxy for loan quality—write-offs—and minimum capital requirements, and find none. Furthermore, we re-

Table 5
Estimates of Model (1) and (2) – controlling for lags of writeoffs.

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.076***	−0.071***	−0.056**	−0.047**	−0.066**	−0.055**
	0.002	0.004	0.018	0.034	0.021	0.037
ΔWriteoffs	0.00556	0.00617	0.00612	0.00581	0.00625	0.00594
	0.180	0.114	0.117	0.134	0.104	0.126
ΔBankRate	−0.0139	−0.05**	−0.049**	−0.055***	−0.062**	−0.072***
	0.420	0.0153	0.02	0.009	0.016	0.005
Inflation		0.0203	0.0219	0.0206	0.0217	0.0202
		0.414	0.382	0.403	0.387	0.412
Real GDP growth		0.078*	0.078*	0.07	0.097**	0.089
		0.061	0.061	0.092*	0.045	0.072*
ΔLoanDem	0.026**	0.029**	0.029**	0.028**	0.028**	0.027**
	0.039	0.0194	0.0207	0.0226	0.0182	0.0197
ΔCapReq*ΔBankrate			0.112	0.0810	0.0917	0.0467
			0.182	0.404	0.370	0.723
ΔBankrate*Liq				0.0674		0.0851
				0.260		0.168
GDP growth*Liq				0.128		0.108
				0.386		0.470
ΔCapReq*Liq				−0.0992		−0.0904
				0.787		0.806
ΔCapReq*ΔBankrate*Liq				0.110		0.145
				0.811		0.755
ΔCapReq* SIZE					0.0530	0.0411
					0.242	0.353
ΔBankrate*SIZE					0.042*	0.053**
					0.08	0.028
GDP growth *SIZE					−0.068*	−0.062*
					0.0592	0.0945
ΔCapReq*ΔBankrate*SIZE					−0.00837	0.0359
					0.941	0.799
Constant	0.00182	−0.0690	−0.0690	−0.0718	−0.0690	−0.0712
	(0.00967)	(0.0482)	(0.0482)	(0.0477)	(0.0479)	(0.0476)
Observations	1805	1805	1805	1805	1805	1805
R-squared	0.026	0.033	0.038	0.048	0.042	0.051
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq and ΔBankrate are the quarterly changes in the banking book capital requirement and Bank Rate, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. ΔWriteoffs is the sum of the contemporaneous and three lags of the change in the writeoff to risk-weighted asset ratio. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

estimate Tables 3 and 4, alternatively with either lags (Tables 5 and 7) or leads (Tables 6 and 8) of changes in the ratio of writeoffs to risk-weighted assets. While the lags of the changes in writeoffs are statistically significant, including those effects has no effect on our previous results regarding the effects of capital requirements on loan supply (as would be expected if loan quality were driving both regulatory changes and loan growth). Leads of writeoffs do not have a statistically significant effect on lending growth.

In the absence of strong instrumental variables it is difficult to definitively rule out endogeneity bias. But in light of the institutional setup of the FSA, the striking similarity between the panel VAR and single equation estimates, and the robustness of our results to the inclusion of leads and lags of writeoffs, it seems unlikely that our estimates are contaminated by serious endogeneity bias.

7. Conclusion

Following the global financial crisis, policy makers around the world are now discussing ways to strengthen capital requirements, and to use them not only as a microeconomic prudential tool, but also as a macro-prudential tool to preserve the stability of the financial system by, *inter alia*, smoothing the credit cycle. With multiple policy instruments for leaning

Table 6
Estimates of Model (1) and (2) – controlling for leads of writeoffs

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.08***	−0.074***	−0.061**	−0.051**	−0.064**	−0.053*
	0.00130	0.0035	0.014	0.024	0.028	0.05
ΔWriteoffs	−0.000175	−0.000175	−0.000175	−0.000169	−0.000170	−0.000171
	0.251	0.246	0.248	0.285	0.255	0.277
ΔBankRate	−0.0133	-0.052**	−0.051**	−0.059***	−0.069**	−0.084***
	0.481	0.018	0.023	0.008	0.012	0.00252
Inflation		0.0144	0.0163	0.0155	0.0159	0.0147
		0.578	0.533	0.548	0.547	0.572
Real GDP growth		0.072*	0.073*	0.065	0.094*	0.087*
		0.0934	0.0940	0.128	0.0626	0.0898
ΔLoanDem	0.025**	0.027**	0.027**	0.027**	0.026**	0.026**
	0.049	0.028	0.03	0.032	0.026	0.027
ΔCapReq*ΔBankrate			0.0980	0.0650	0.0906	0.0450
			0.252	0.518	0.378	0.731
ΔBankrate*Liq				0.0835		0.11*
				0.162		0.079
GDP growth*Liq				0.115		0.0922
				0.435		0.537
ΔCapReq*Liq				−0.113		−0.109
				0.755		0.766
ΔCapReq*ΔBankrate*Liq				0.104		0.127
				0.819		0.783
ΔCapReq* SIZE					0.0363	0.0246
					0.340	0.506
ΔBankrate*SIZE					0.059**	0.074***
					0.033	0.0086
GDP growth *SIZE					−0.078**	−0.073*
					0.0372	0.0580
ΔCapReq*ΔBankrate*SIZE					−0.00541	0.0400
					0.962	0.775
Constant	0.000321	−0.0635	−0.0637	−0.0672	−0.0633	−0.0658
	(0.00957)	(0.0497)	(0.0498)	(0.0494)	(0.0497)	(0.0494)
Observations	1715	1715	1715	1715	1715	1715
R-squared	0.027	0.034	0.039	0.048	0.042	0.052
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq and ΔBankrate are the quarterly changes in the banking book capital requirement and Bank Rate, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. ΔWriteoffs is the sum of the contemporaneous and three leads of the change in the writeoff to risk-weighted asset ratio. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

against the credit cycle, some of the fundamental questions that arise are: (1) what is the relative strength of each instrument; (2) how do they interact; and (3) what contingencies (cross-sectional differences or changes over time) affect the potency of each instrument? Theoretical contributions have argued that monetary policy will tend to be better able to achieve price stability objectives, and that capital requirement policy (and more generally, macro-prudential policies), will tend to be better able to achieve financial stability objectives. Theoretical models also have stressed potentially important contingencies that may affect the potency of these tools (e.g., due to cross-time differences in the term premium, or cross-sectional differences in banks' costs of raising non-depository debt or outside equity) and have posited important interactions between monetary policy and capital requirement policy.

In this study, we address these three sets of questions by examining how monetary policy and changes in minimum capital ratio requirements affect bank loan supply. We exploit a unique UK data set on bank-specific, time-varying capital requirements together with bank lending data in what we believe to be the first microeconomic study of the joint operation of monetary policy and changes in capital requirements.

Consistent with previous work, we find that capital requirement policy is a more powerful tool for achieving financial stability objectives related to loan supply. Monetary policy has a powerful effect on the loan supply of small banks but not of large banks. In contrast, capital requirements substantially affect the loan supply of both large and small banks. Unlike small banks, large banks appear to be able to access non-depository debt markets to insulate their loan supply from monetary

Table 7
Estimates of Model (3) – controlling for lags of writeoffs.

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.076***	−0.07***	−0.057*	−0.049*	−0.065*	−0.057*
	0.00188	0.004	0.0616	0.0791	0.0639	0.0864
ΔWriteoffs	0.00556	0.00617	0.00613	0.00588	0.00623	0.00599
	0.180	0.114	0.117	0.130	0.107	0.125
ΔBankrate	−0.0139	−0.05**	−0.052**	−0.056***	−0.066**	−0.075***
	0.420	0.0153	0.0145	0.0074	0.0114	0.00466
Inflation		0.0203	0.0217	0.0209	0.0208	0.0199
		0.414	0.385	0.395	0.408	0.421
Real GDP growth		0.078*	0.078*	0.069*	0.096**	0.086*
		0.0611	0.0590	0.0866	0.0466	0.0748
ΔLoanDem	0.026**	0.029**	0.028**	0.028**	0.027**	0.027**
	0.0399	0.0194	0.0213	0.0233	0.0186	0.0202
ΔCapReq*ΔBankrate *ΔTerm			−0.267	0.0130	0.0480	−0.0496
			0.755	0.963	0.864	0.888
ΔBankrate*Liq				0.0652		0.0845
				0.294		0.187
GDP growth*Liq				0.124		0.106
				0.394		0.472
ΔCapReq*Liq				−0.135		−0.127
				0.677		0.697
ΔCapReq*ΔBankrate *ΔTerm*Liq				0.0992		0.133
				0.754		0.716
ΔCapReq* SIZE					0.0456	0.0363
					0.416	0.518
ΔBankrate*SIZE					0.044*	0.054**
					0.0689	0.0297
GDP growth *SIZE					−0.069*	−0.061*
					0.0564	0.0962
ΔCapReq*ΔBankrate *ΔTerm *SIZE					0.378	−0.0122
					0.746	0.975
Constant	0.00182	−0.0690	−0.0702	−0.0727	−0.0683	−0.0702
	(0.00967)	(0.0482)	(0.0482)	(0.0474)	(0.0481)	(0.0475)
Observations	1805	1805	1805	1805	1805	1805
R-squared	0.026	0.033	0.039	0.049	0.042	0.052
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq, ΔBankrate and ΔTerm are the quarterly changes in the banking book capital requirement, Bank Rate and the term premium, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. ΔWriteoffs is the sum of the contemporaneous and three lags of the change in the writeoff to risk-weighted asset ratio. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

policy shocks that raise the cost of funding loans with deposits. Large banks also seem to be able to insulate their funding costs from other cyclical shocks that affect the loan-supply of small banks. This difference in banks' ability to access debt markets has important implications for the relative potency and distributional consequences of the two primary policy instruments that can be used to control lending: monetary policy and minimum capital requirements.

The magnitude of the estimated effects of bank capital requirements is large in our sample. The negative elasticity of the response of loan supply to an increase in capital requirements is typically greater than one half. Given large banks' apparent facility in switching between deposit and non-deposit sources of finance in response to monetary policy shocks, and given the concentration of the UK banking system, our results suggest that minimum capital requirement changes might offer a more potent tool for improving the resilience of the financial system, by moderating bank lending, over the cycle. Of course, there are numerous other channels through which monetary policy affects the real economy. Our study is confined to identifying only the effects of monetary policy on the bank lending channel.

Other theoretically posited implications are not confirmed in our analysis. We do not find evidence of important interaction effects between monetary policy and capital requirements policy, nor do we find that such an interaction effect varies with the term premium.

Table 8
Estimates of Model (3) – controlling for leads of writeoffs.

	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq	−0.078***	−0.07***	−0.057*	−0.048*	−0.062*	−0.053
	0.0016	0.004	0.067	0.097	0.083	0.127
ΔWriteoffs	−0.004	−0.003	−0.003	−0.003	−0.002	−0.003
	(0.07)	(0.03)	(0.04)	(0.05)	(0.03)	(0.04)
ΔBankrate	−0.0123	−0.052*	−0.054*	−0.061***	−0.072***	−0.086***
	0.515	0.0199	0.0181	0.007	0.009	0.002
Inflation		0.0153	0.0168	0.0174	0.0154	0.0156
		0.555	0.521	0.503	0.559	0.552
Real GDP growth		0.073*	0.074*	0.0662	0.094*	0.085*
		0.09	0.086	0.115	0.0632	0.0906
ΔLoanDem	0.026**	0.028**	0.027**	0.027**	0.026**	0.026**
	0.0484	0.028	0.03	0.03	0.0252	0.0263
ΔCapReq*ΔBankrate *ΔTerm			−0.271	−0.000870	0.0374	−0.0652
			0.772	0.998	0.892	0.849
ΔBankrate*Liq				0.0947		0.120
				0.124		0.0601
GDP growth*Liq				0.122		0.101
				0.417		0.509
ΔCapReq*Liq				−0.150		−0.143
				0.645		0.661
ΔCapReq*ΔBankrate *ΔTerm*Liq				0.402		0.471
				0.741		0.703
ΔCapReq* SIZE					0.0162	0.00567
					0.738	0.908
ΔBankrate*SIZE					0.062**	0.076***
					0.027	0.0086
GDP growth *SIZE					−0.08**	−0.072*
					0.0339	0.0581
ΔCapReq*ΔBankrate *ΔTerm *SIZE					0.351	−0.0857
					0.568	0.823
Constant	0.000318	−0.0645	-0.0659	-0.0705	−0.0631	−0.0668
	(0.00960)	(0.0498)	(0.0497)	(0.0491)	(0.0499)	(0.0493)
Observations	1715	1715	1715	1715	1715	1715
R-squared	0.027	0.034	0.040	0.051	0.044	0.055
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq, ΔBankrate and ΔTerm are the quarterly changes in the banking book capital requirement, Bank Rate and the term premium, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. ΔWriteoffs is the sum of the contemporaneous and three leads of the change in the writeoff to risk-weighted asset ratio. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.

* $p<0.1$.
** $p<0.05$.
*** $p<0.01$.

Table 9
Comparing the impact of monetary and capital requirement policy on lending growth.

Impact of monetary policy	Table – 3		Table-4		Table-5		Table-6		Table–7		Table-8		**Mean**
Specification	5	6	5	6	5	6	5	6	5	6	5	6	
Large Bank	−2	−2.1	−1.75	−2.15	−2	−1.9	−.9	−1	−2.2	−2.1	−1	−1	−**1.7**
Small Bank	−6	−7.1	−6	−7.4	−6.2	−7.2	−6.8	−8.3	−6.6	−7.5	−7.2	−8.6	−**7.1**
Overall	−2.5	−2.7	−2.3	−2.8	−2.5	−2.6	−1.6	−1.9	−2.7	−2.8	−1.8	−1.9	−**2.35**
Impact of capital requirement policy	Table-3		Table-4		Table-5		Table-6		Table – 7		Table-8		**Mean**
Specification	5	6	5	6	5	6	5	6	5	6	5	6	
Large Bank	−6.7	−5.6	−6	−5.7	−6.6	−5.5	−6.3	−5	−6.5	−5.7	−6.2	−5.3	−**5.9**
Small Bank	−6.7	−5.6	−6	−5.7	−6.6	−5.5	−6.3	−5	−6.5	−5.7	−6.2	−5.3	−**5.9**
Overall	−6.7	−5.6	−6	−5.7	−6.6	−5.5	−6.3	−5	−6.5	−5.7	−6.2	−5.3	−**5.9**

Note: In the UK small banks make up 12.5% of the total lending, while large banks make 87.5%. Correspondingly, these are the weight attached to small and large banks for monetary policy. For capital requirements policy there is no difference due to the absence of a statistically significant interaction term on bank size.

Table 10
Comparing PVAR to baseline model estimates.

	Sum of Loan Growth IRF to ΔCapReq in Bi-Variate Panel VAR			Sum of Loan Growth IRF to ΔCapReq in Tri-Variate Panel VAR			Baseline model coefficients
Quantiles	5th	50th	95th	5th	50th	95th	50th
Impact	−0.0518	−0.03273	−0.01547	−0.05108	−0.03273	−0.01259	−0.03739
Period 1	−0.03669	−0.01906	−0.0018	−0.03633	−0.01942	−0.00216	−0.01793
Period 2	−0.0295	−0.01367	0.003237	−0.03022	−0.01259	0.003237	−0.00996
Period 3	−0.02338	−0.00755	0.007914	−0.01906	−0.00719	0.006835	−0.00397
Sum	−0.14137	−0.07302	−0.00612	−0.13669	−0.07194	-0.00468	−0.06925

Note: This table shows the 5th, 50th and 95th quantiles of impulse responses from the panel VAR upon impact and for three periods thereafter. The final row shows the sum. The final column shows the individual coefficients from a simple panel regression where the impact and three lagged changes in capital requirements were regressed on the loan growth (in other words, a restricted version of the panel VAR). The final row shows the sum of these coefficients.

Appendix A

This appendix shows how to compare VAR impulse response functions and coefficients from dynamic structural models to assess the presence of simultaneity issues. For ease of notation, we derive all of our results for time-series models, but we note that they easily carry over to dynamic panel data models.

A simplified version of our baseline regression model is:

$$\Delta L_t = \alpha \Delta \mathrm{CaptReq}_t + \gamma_1 \Delta CapReq_{t-1} + \gamma_2 \Delta CapReq_{t-2} + \gamma_3 \Delta CapReqR_{t-3} + e_t$$

The estimate that is reported in the regression tables in the paper is: $\alpha^{Base} + \gamma_1 + \gamma_2 + \gamma_3$. If there is an endogeneity problem, α^{Base} will be badly biased. A less restricted empirical model would be a VAR:

$$\Delta CapReq_t = \beta_1 \Delta CapReq_{t-1} + \beta_2 \Delta CapReq_{t-2} + \beta_3 \Delta CapReq_{t-3} + \beta_4 \Delta L_{t-1} + \beta_5 \Delta L_{t-2} + \beta_6 \Delta L_{t-3} + e_t^{CR}$$

$$\Delta L_t = \gamma_1 \Delta \mathrm{CapReq}_{t-1} + \gamma_2 \Delta \mathrm{CapReq}_{t-2} + \gamma_3 \Delta \mathrm{CapReq}_{t-3} + \gamma_4 \Delta L_{t-1} + \gamma_5 \Delta L_{t-2} + \gamma_6 \Delta L_{t-3} + e_t^L$$

Now lets write this in matrix format:

$$[\Delta \mathrm{CapReq}_t \ \Delta L_t] = \begin{bmatrix} \beta_1 & \beta_4 \\ \gamma_1 & \gamma_4 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-1} \ \Delta L_{t-1}] + \begin{bmatrix} \beta_2 & \beta_5 \\ \gamma_2 & \gamma_5 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-2} \ \Delta L_{t-2}] + \begin{bmatrix} \beta_3 & \beta_6 \\ \gamma_3 & \gamma_6 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-3} \ \Delta L_{t-3}] + [e_t^{CR} e_t^L]$$

now note that for identification, we impose a lower triangular i.e.

$$[e_t^{CR} \ e_t^L] = \overbrace{\begin{bmatrix} 1 & 0 \\ \alpha^{VAR} & 1 \end{bmatrix}}^{A} [\epsilon_t^{CR} \ \epsilon_t^L]$$

where ε_t^{CR} is the structural capital requirements shock. Note that α^{VAR} is an unbiased estimate of the contemporeneous relationship between ΔL_t and $\Delta \mathrm{CapReq}_t$. The can then be rewritten in structural form by pre-multipling the whole system of equations by A^{-1}.

$$\begin{aligned} \overbrace{\begin{bmatrix} 1 & 0 \\ \alpha^{VAR} & 1 \end{bmatrix}}^{A-1} [\Delta \mathrm{CapReq}_t \ \Delta L_t] = \begin{bmatrix} 1 & 0 \\ -\alpha^{VAR} & 1 \end{bmatrix} \begin{bmatrix} \beta_1 & \beta_4 \\ \gamma_1 & \gamma_4 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-1} \ \Delta L_{t-1}] \\ + \begin{bmatrix} 1 & 0 \\ -\alpha^{VAR} & 1 \end{bmatrix} \begin{bmatrix} \beta_2 & \beta_5 \\ \gamma_2 & \gamma_5 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-2} \ \Delta L_{t-2}] \\ + \begin{bmatrix} 1 & 0 \\ -\alpha^{VAR} & 1 \end{bmatrix} \begin{bmatrix} \beta_3 & \beta_6 \\ \gamma_3 & \gamma_6 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-3} \ \Delta L_{t-3}] + \begin{bmatrix} 1 & 0 \\ -\alpha^{VAR} & 1 \end{bmatrix} [e_t^{CR} e_t^{CR} \ e_t^L] \end{aligned}$$

which simplifies to:

$$\begin{aligned} [\Delta \mathrm{Cap}Req_t \ \Delta L_t] = \left[0 \ \alpha^{VAR}\right] \Delta \mathrm{CapReq}_t + \begin{bmatrix} \beta_1 & \beta_4 \\ \gamma_1 - \alpha^{VAR}\beta_1 & \gamma_4 - \alpha^{VAR}\beta_4 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-1} \ \Delta L_{t-1}] \\ + \begin{bmatrix} \beta_2 & \beta_5 \\ \gamma_2 - \alpha^{VAR}\beta_2 & \gamma_5 - \alpha^{VAR}\beta_5 \end{bmatrix} [\Delta \mathrm{CapReq}_{t-2} \Delta L_{t-2}] \end{aligned}$$

$$+\begin{bmatrix}\beta_3 & \beta_6\\ \gamma_3-\alpha^{VAR}\beta_3 & \gamma_6-\alpha^{VAR}\beta_6\end{bmatrix}\left[\Delta\text{CapReq}_{t-3}\ \Delta L_{t-3}\right]+\left[\epsilon_t^{CR}\ \epsilon_t^{L}\right]$$

Now we can do some impulse response analysis by hand. Lets set $\epsilon_t^{CR}=1$ at time period 0 and then iterate for three periods. So the impact of ϵ_t^{CR} on ΔL_t at time 0 is:

$$\Delta L_0=\alpha^{VAR}\Delta\text{CaqReq}_0=\alpha^{VAR}\epsilon_t^{KR}=\alpha^{VAR}$$

at time 1 it is

$$\Delta L_1=\alpha^{VAR}\Delta CapReq_1+\left(\gamma_1-\alpha^{VAR}\beta_1\right)\Delta CapReq_0+\left(\gamma_4-\alpha^{VAR}\beta_4\right)\Delta L_0$$

$$=\alpha^{VAR}(\beta_1\Delta\text{CapReq}_0+\beta_4\Delta L_0)+\left(\gamma_1-\alpha^{VAR}\beta_1\right)\Delta\text{CapReq}_0+\left(\gamma_4-\alpha^{VAR}\beta_4\right)\Delta L_0$$

$$=\gamma_1\Delta\text{CapReq}_0+\gamma_4\Delta L_0=\gamma_1+\gamma_4\alpha^{VAR}$$

at time 2 it is

$$\Delta L_2=\alpha^{VAR}\Delta\text{CapReq}_2+\left(\gamma_1-\alpha^{VAR}\beta_1\right)\Delta\text{CapReq}_1+\left(\gamma_4-\alpha^{VAR}\beta_4\right)\Delta L_1+\left(\gamma_2-\alpha^{VAR}\beta_2\right)\Delta\text{CapReq}_0+\left(\gamma_5-\alpha^{VAR}\beta_5\right)\Delta L_0$$

$$=\alpha^{VAR}(\beta_1\Delta\text{CapReq}_1+\beta_4\Delta L_1+\beta_2\Delta\text{CapReq}_0+\beta_5\Delta L_0)+\left(\gamma_1-\alpha^{VAR}\beta_1\right)\Delta\text{CapReq}_1$$

$$+\ \left(\gamma_4-\alpha^{VAR}\beta_4\right)\Delta L_1+\left(\gamma_2-\alpha^{VAR}\beta_2\right)\Delta\text{CapReq}_0+\left(\gamma_5-\alpha^{VAR}\beta_5\right)\Delta L_0$$

$$=\gamma_1\Delta\text{CapReq}_1+\gamma_4\Delta L_1+\gamma_2\Delta\text{CapReq}_0+\gamma_5\Delta L_0$$

$$=\gamma_1\left(\beta_1+\beta_4\alpha^{VAR}\right)+\gamma_4\left(\gamma_1+\gamma_4\alpha^{VAR}\right)+\gamma_2+\gamma_5\alpha^{VAR}$$

at time 3 it is:

$$\Delta L_3=\alpha^{VAR}\Delta\text{CapReq}_3+\left(\gamma_1-\alpha^{VAR}\beta_1\right)\Delta\text{CapReq}_2+\left(\gamma_4-\alpha^{VAR}\beta_4\right)\Delta L_2+\left(\gamma_2-\alpha^{VAR}\beta_2\right)\Delta\text{CapReq}_1+\left(\gamma_5-\alpha^{VAR}\beta_5\right)\Delta L_1$$

$$=\alpha^{VAR}(\beta_1\Delta\text{CapReq}_2+\beta_4\Delta L_2+\beta_2\Delta\text{CapReq}_1+\beta_5\Delta L_1+\beta_3\Delta\text{CapReq}_0+\beta_4\Delta L_0)+\left(\gamma_1-\ \alpha^{VAR}\beta_1\right)\Delta\text{CapReq}_2$$

$$+(\gamma_4-\alpha^{VAR}\beta_4)\Delta L_2+(\gamma_2-\alpha^{VAR}\beta_2)\Delta\text{CapReq}_1+(\gamma_5-\alpha^{VAR}\beta_5)\Delta L_1+(\gamma_3-\ \alpha^{VAR}\beta_3)\Delta\text{CapReq}_0+(\gamma_6-\alpha^{VAR}\beta_6)\Delta L_0$$

$$=\gamma_1\Delta\text{CapReq}_2+\gamma_4\Delta L_2+\gamma_2\Delta\text{CapReq}_1+\gamma_5\Delta L_1+\gamma_3\Delta\text{CapReq}_0+\gamma_6\Delta L_0$$

$$=(\gamma_1\beta_1^2+\gamma_2\beta_1+\gamma_1\beta_2+\gamma_3)+(\gamma_1\beta_1\beta_4+\gamma_2\beta_4+\gamma_1\beta_5+\gamma_6)\alpha^{VAR}$$

$$+\gamma_2(\gamma_1\beta_4+\gamma_5)\left(\gamma_1+\gamma_4\alpha^{VAR}\right)+\gamma_4\left(\gamma_1\left(\beta_1+\beta_4\alpha^{VAR}\right)+\gamma_4\left(\gamma_1+\gamma_4\alpha^{VAR}\right)+\gamma_5\alpha^{VAR}\right)$$

Summing up the impulse responses over impact+three periods gives:

$$\Delta L_0+\Delta L_1+\Delta L_2+\Delta L_3$$

$$=\alpha^{VAR}+\gamma_1+\gamma_4\alpha^{VAR}+\gamma_1(\beta_1+\beta_4\alpha^{VAR})+\gamma_4(\gamma_1+\gamma_4\alpha^{VAR})+\gamma_2+\gamma_5\alpha^{VAR}$$

$$+(\gamma_1\beta_1^2+\gamma_2\beta_1+\gamma_1\beta_2+\gamma_3)+(\gamma_1\beta_1\beta_4+\gamma_2\beta_4+\gamma_1\beta_5+\gamma_6)\alpha^{VAR}$$

$$+\gamma_2(\gamma_1\beta_4+\gamma_5)(\gamma_1+\gamma_4\alpha^{VAR})+\gamma_4(\gamma_1(\beta_1+\beta_4\alpha^{VAR})+\gamma_4(\gamma_1+\gamma_4\alpha^{VAR})+\gamma_5\alpha^{VAR})$$

Under the following assumptions:

i. Lending growth is not autoregressive → $\gamma_4=\gamma_5=\gamma_6=0$
ii. The lags of Lending growth never affect the change in CapReq (ΔL_t does not granger cause $\Delta CapReq_t$) → $\beta_4=\beta_5=\beta_6=0$
iii. The change in Capital requirements is not auto regressive → $\beta_1=\beta_2=\beta_3=0$
iv. There is no endogeneity bias: $\alpha^{Base}=\ \alpha^{VAR}$

Then the above expression simplifies to $\alpha^{Base}+\gamma_1+\gamma_2+\gamma_3$, which is precisely the estimate we reported in the regression tables throughout our paper.

In other words, if the cumulant of the impact and first three periods of the Impulse Response Function coincide, that is strong evidence that simultaneity bias is not issue. This is what we find in our paper.

Appendix B

See Tables B1 and B2.

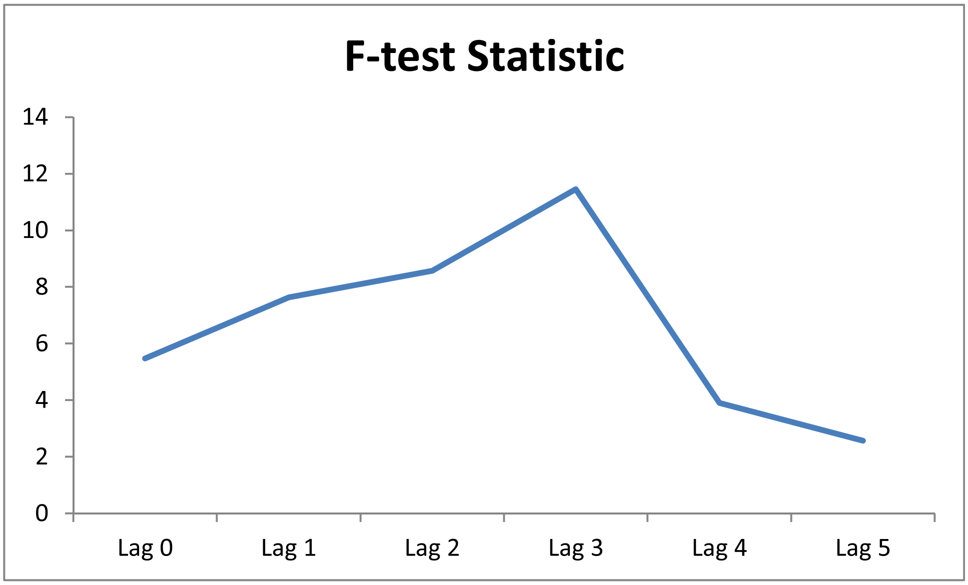

Table B1
Estimates of Model (1) and (2) – Lending –with lagged dependent VAR.

	(1)	(2)	(3)	(4)	(5)	(6)
Lagged Loan Growth	−0.105**	−0.110**	−0.111**	−0.114**	−0.112**	−0.116**
	0.0478	0.0472	0.0474	0.0482	0.0477	0.0484
ΔCapReq	−0.085***	−0.08***	−0.062**	−0.052**	−0.073**	−0.061**
(Prob > *F*)	0.000863	0.00187	0.0109	0.0261	0.0141	0.0324
ΔBankrate	−0.0122	−0.052**	−0.051**	−0.059***	−0.063**	−0.08***
(Prob > *F*)	0.484	0.0126	0.0169	0.00497	0.0138	0.00223
Inflation		0.0229	0.0248	0.0242	0.0247	0.0239
		0.376	0.340	0.350	0.342	0.356
Real GDP growth		0.088**	0.089**	0.077*	0.11**	0.099*
		0.0427	0.0421	0.0743	0.029	0.057
ΔLoanDem	0.027**	0.031**	0.031**	0.031**	0.031**	0.03**
	0.0384	0.0169	0.0179	0.0190	0.0157	0.0157
ΔCapReq*ΔBankrate			0.127	0.0931	0.109	0.0587
			0.158	0.363	0.324	0.674
ΔBankrate*Liq				0.0533		0.0741
				0.299		0.169
GDP growth*Liq				0.0973		0.0751
				0.377		0.509
ΔCapReq*Liq				0.00112		0.0105
				0.997		0.969
ΔCapReq*ΔBankrate*Liq				0.211		0.247
				0.595		0.546
ΔCapReq* SIZE					0.0596	0.0471
					0.195	0.300
ΔBankrate*SIZE					0.042*	0.059**
					0.0988	0.0241
GDP growth *SIZE					−0.078**	−0.068*
					0.045	0.0945
ΔCapReq*ΔBankrate*SIZE					−0.0214	0.0286
					0.858	0.847
Constant	0.00139	−0.0779	−0.0786	−0.0809	−0.0790	−0.0805
	(0.00968)	(0.0486)	(0.0486)	(0.0489)	(0.0483)	(0.0486)
Observations	1815	1815	1815	1815	1815	1815

Table B1 (*continued*)

	(1)	(2)	(3)	(4)	(5)	(6)
R-squared	0.034	0.042	0.047	0.058	0.050	0.062
Number of banks	82	82	82	82	82	82

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq and ΔBankrate are the quarterly changes in the banking book capital requirement and Bank Rate, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table B2
Estimates of Model with different KR lags.

Individual Coefficients	(1)	(2)	(3)	(4)	(5)	(6)
ΔCapReq (0)	−0.037**	−0.0376**	−0.0378**	−0.0384**	−0.0349*	−0.0388
	(0.0157)	(0.0154)	(0.0155)	(0.0154)	(0.0209)	(0.0245)
ΔCapReq (1)		−0.0140	−0.0146	−0.0150	−0.0138	−0.0150
		(0.0151)	(0.0148)	(0.0149)	(0.0159)	(0.0215)
ΔCapReq (2)			−0.0114	−0.0123	−0.00873	−0.00710
			(0.0133)	(0.0133)	(0.0126)	(0.0131)
ΔCapReq (3)				−0.0144**	−0.0185**	−0.0191**
				(0.00682)	(0.00811)	(0.00841)
ΔCapReq (4)					0.0162	0.0118
					(0.0135)	(0.0113)
ΔCapReq (5)						0.0116
ΔLoanDem (0)	0.0578*	0.0581*	0.0584*	0.0587*	0.0634*	0.0610*
	(0.0343)	(0.0342)	(0.0342)	(0.0341)	(0.0357)	(0.0348)
ΔLoanDem (1)	−0.0571	−0.0569	−0.0571	−0.0570	−0.0620	−0.0601
	(0.0394)	(0.0395)	(0.0394)	(0.0394)	(0.0408)	(0.0400)
ΔLoanDem (2)	0.0671**	0.0673**	0.0676**	0.0680**	0.0701**	0.0738**
	(0.0291)	(0.0291)	(0.0290)	(0.0288)	(0.0296)	(0.0309)
ΔLoanDem (3)	−0.047**	−0.0469**	−0.0472**	−0.0473**	−0.0548**	-0.0603***
Sum of Coefficients						
ΔCapReq	−0.037**	−0.052***	−0.064***	−0.08***	−0.06*	−0.057
F-STAT	5.478	7.637	8.565	11.45	3.896	2.563
(Prob > *F*)	0.0217	0.00708	0.00445	0.00111	0.0520	0.114
ΔLoanDem	0.0213	0.0216	0.0218	0.0224	0.0167	0.0145
F-STAT	3.436	3.596	3.648	3.785	2.086	2.059
(Prob > *F*)	0.0674	0.0615	0.0597	0.0552	0.153	0.155
Constant	0.00139	−0.0779	−0.0786	−0.0809	−0.0790	−0.0805
	(0.00968)	(0.0486)	(0.0486)	(0.0489)	(0.0483)	(0.0486)
Observations	1815	1815	1815	1815	1722	1637
R-squared	0.019	0.020	0.020	0.021	0.023	0.024
Number of banks	82	82	82	82	77	77

We report the sum of for contemporaneous and lagged coefficients of each variable, with the corresponding *F*-statistics provided in parentheses. ΔCapReq and ΔBankrate are the quarterly changes in the banking book capital requirement and Bank Rate, respectively. Inflation and real GDP growth are quarterly growth rates of the GDP deflator and real GDP. ΔLoanDem is the loan demand variable described in the main text. SIZE is a dummy variable taking the value of 1, and 0 otherwise, if the time average of the banks size relative to the banking system is in the top 15% of the distribution. Similarly, Liq is a dummy variable taking the value of 1, and 0 otherwise, if a banks time average liquid to total asset ratio is in the top 15% of the distribution.
All regressions include bank fixed effects.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

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