DISCUSSION PAPER SERIES

DP11265

THE REAL EFFECTS OF CAPITAL REQUIREMENTS AND MONETARY POLICY: EVIDENCE FROM THE UNITED KINGDOM

Filippo De Marco and Tomasz Wieladek

FINANCIAL ECONOMICS and MONETARY ECONOMICS AND FLUCTUATIONS

ISSN 0265-8003

THE REAL EFFECTS OF CAPITAL REQUIREMENTS AND MONETARY POLICY: EVIDENCE FROM THE UNITED KINGDOM

Filippo De Marco and Tomasz Wieladek

Discussion Paper 11265
Published 09 May 2016
Submitted 09 May 2016

Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

THE REAL EFFECTS OF CAPITAL REQUIREMENTS AND MONETARY POLICY: EVIDENCE FROM THE UNITED KINGDOM

Abstract

We study the effects of bank-specific capital requirements on Small and Medium Enterprises (SMEs) in the UK from 1998 to 2006. Following a 1% increase in capital requirements, SMEs' asset growth contracts by 6.9% in the first year of a new bank-firm relationship, but the effect declines over time. We also compare the effects of capital requirements to those of monetary policy. Monetary policy only affects firms with higher credit risk and those borrowing from small banks, whereas capital requirements affect both. Capital requirement changes, instead, do not affect firms with alternative sources of finance, but monetary policy shocks do.

JEL Classification: G21, G28, E51

Keywords: Capital requirements, Firm-level real effects, SMEs, relationship lending, prudential and monetary policy.

Filippo De Marco - filippo.demarco@unibocconi.it
Bocconi University and IGIER, Department of Finance.

Tomasz Wieladek - tomaszwieladek@gmail.com
Barclays and CEPR

Acknowledgements
We are grateful to Steffen Andersen (discussant), Susanto Basu, Thorsten Beck, Martin Brown, Stijn Claessens, Ralph De Haas, Giovanni Dell'Arricia, Irem Demirci (discussant), Simon Gilchrist (discussant), Ali Hortacsu, Garry Young, José-Luis Peydró, Manju Puri (discussant), Philip Strahan, Fabio Schiantarelli and seminar or conference participants at Boston College, Bank of England, BU-BC Green Line Macro Meeting, IMF, 15th FDIC-JFSR Annual Bank Research Conference, Bundesbank "Financial Intermediaries and the Real Economy", CEPR "Finance, Capital Reallocation and Growth" in St.Gallen, 12th EWFS in Davos for helpful suggestions. A special thank goes to Arzu Uluc for her assistance in the final stages of the project. Filippo De Marco gratefully acknowledges financial support from the Baffi-CAREFIN Centre. All remaining errors are our own.

The Real Effects of Capital Requirements and Monetary Policy: Evidence from the United Kingdom

Filippo De Marco[(1)] and Tomasz Wieladek [(2)]

April 2016

Abstract
We study the effects of bank-specific capital requirements on Small and Medium Enterprises (SMEs) in the UK from 1998 to 2006. Following a 1% increase in capital requirements, SMEs' asset growth contracts by 6.9% in the first year of a new bank-firm relationship, but the effect declines over time. We also compare the effects of capital requirements to those of monetary policy. Monetary policy only affects firms with higher credit risk and those borrowing from small banks, whereas capital requirements affect both. Capital requirement changes, instead, do not affect firms with alternative sources of finance, but monetary policy shocks do.

Key words: Capital requirements, Firm-level real effects, SMEs, relationship lending, prudential and monetary policy.

***JEL* classification**: G21, G28, E51

---

(1) Bocconi University and IGIER, Department of Finance, Via Roentgen 1, 20136 Milan (Italy). Email: filippo.demarco@unibocconi.it
(2) Wieladek is Senior International Economist at Barclays and CEPR Research Affiliate. His contribution to this paper was completed while employed by the Bank of England and does not represent the views of Barclays.

We are grateful to Steffen Andersen (discussant), Susanto Basu, Thorsten Beck, Martin Brown, Stijn Claessens, Ralph De Haas, Giovanni Dell'Arricia, Irem Demirci (discussant), Simon Gilchrist (discussant), Ali Hortacsu, Garry Young, José-Luis Peydró, Manju Puri (discussant), Philip Strahan, Fabio Schiantarelli and seminar or conference participants at Boston College, Bank of England, BU-BC Green Line Macro Meeting, IMF, 15th FDIC-JFSR Annual Bank Research Conference, Bundesbank "Financial Intermediaries and the Real Economy", CEPR "Finance, Capital Reallocation and Growth" in St.Gallen, 12th EWFS in Davos for helpful suggestions. A special thank goes to Arzu Uluc for her assistance in the final stages of the project. Filippo De Marco gratefully acknowledges financial support from the Baffi-CAREFIN Centre. All remaining errors are our own.

Introduction

Do higher capital requirements affect the real economy? While this question is at the heart of the current debate about the social costs and benefits of increasing capital requirements under Basel III, empirical evidence is still scarce (Galati and Moessner (2014), Jimenez et al. (2015)), since capital requirements in most countries were kept constant in the past. One exception was the UK, where the Financial Services Authority (FSA), the bank regulator between 1998 and 2006, imposed *bank-specific* capital requirements and adjusted them *over time*. In this paper we test if these capital requirement changes affect the asset growth and tangible investment of Small and Medium Enterprises (SMEs) that borrow from the affected banks. We examine whether access to alternative sources of finance, either via capital markets or the presence of foreign branches, not subject to UK capital regulation, can mitigate the impact of prudential policy. We also study the impact of monetary policy on SMEs and compare its effects to those of capital requirement changes. Finally, we test if prudential and monetary policies interact with each other, a topic of great current policy relevance.

If the Miller-Modigliani theorem (1953) fails and capital requirements are a binding constraint on bank's equity, then an increase in capital requirements will result in either an increase in capital or in a reduction in risk-weighted assets (RWA). Indeed, several previous studies on the same UK FSA capital requirements data that we employ in this paper (Aiyar, Calomiris and Wieladek (2014a,b,c), Bridges et al (2014)) find that banks affected by changes in capital requirement decrease RWA by reducing lending to the private sector. All these papers analyse data on lending at the *bank level*. However, due to alternative sources of credit, either from competing banks or capital markets, a contraction in bank-specific lending does not necessarily need to translate to an impact on the real economy. In this paper we can directly test whether this is the case with *matched bank-firm* data.

A second implication of the failure of the Miller-Modigliani theorem for banks is that it is costlier to raise uninsured than insured debt. As a result, monetary policy will affect banks through the bank lending channel (Bernanke and Blinder (1988)). First, we test this hypothesis with a newly constructed measure of monetary policy for the UK based on forecast surprises from a Taylor rule. Second, we compare the differential impact of monetary and prudential policy by bank and firm characteristic. Finally, we explore whether the two policies interact when they are used jointly. The UK experience is helpful in this respect, as the FSA and Bank of England set these instruments independently. This paper allows us to shed further light on this key policy question.

Our results suggest that a one percent rise in capital requirements leads to a decline in asset growth of an SME of about 6.9% in the *first year of a new bank-firm relationship*. The effect dissipates over time, as the length of the relationship increases. This is consistent with the literature on relationship lending that argues that banks, when hit by a shock, would not cut lending to their long-time customers, but rather to the newly acquired borrowers (Bolton et al. (2013)). Investment in tangible assets follows a similar pattern. Next, we explore several transmission mechanisms in interaction with bank and firm characteristics. First, consistent with the idea that capital requirements need to be binding to affect the real economy, we observe that those SMEs that borrow from banks with tight capital buffers experience a larger contraction. Second, no evidence for risk-shifting, *i.e.* the notion that banks with higher capital requirements would lend to ex-ante riskier customers, is found. Third, we test whether alternative sources of finance can mitigate the impact of capital requirements. For example, we find that firms operating in sectors where a significant fraction of lending comes from foreign branches, which are not subject to UK regulation, contract assets by less. Those with *multiple banking relationships*, in contrast to those with single bank relationships, are not affected by capital requirement changes at all. Intuitively, single-bank firms should be more affected by changes in capital requirements as they cannot easily substitute funding away from the affected bank, while firms with multiple banks can. [1]

We then analyse the effects of monetary policy shocks on SMEs: again we find a negative effect for firms with short banking relationships. We then compare monetary policy and capital regulation: the two policies have very heterogeneous effects by type of firms and banks. First of all, we find that only borrowers of small banks are affected by monetary policy shocks. This is consistent with the results in Kashyap and Stein (2000) who show that monetary policy in the US only affects the lending of small banks, as large banks can easily offset a fall in reserves by issuing uninsured debt. Capital requirements, on the other hand, affect both large and small banks. Second, both single and multiple-banking firms are affected by monetary policy shocks, although this is not the case for capital requirements. Third, unlike capital requirements, monetary policy tends to affect riskier firms more, consistent with the *risk-taking channel of monetary policy* (Jimenez et al. (2014) and Dell'Arricia et al (2015)). Fourth, both policies affect the commercial real estate sector, which is highly leveraged, the most. Finally, there is some evidence that these instruments reinforce each other when monetary policy is tightened, but only for small banks.

A potential identification issue in our setup is that capital requirement changes may be endogenous with respect to unobservable bank or firm characteristics. In principle, in fact, the FSA regulatory changes had to address legal, operational and interest rate risks, which were not allowed for in Basel I. In practice, anecdotal evidence suggests that the capital requirements changes for each bank were based on organization structures, IT systems and reporting procedures rather than overall risk. Aiyar et al (2014a,b) argue that for these

[1] It is possible that this would be different with a macro-prudential capital requirement, as opposed to a micro-prudential capital requirement, such as the one that we analyse.

reasons capital requirement changes are orthogonal to balance sheet risks. In this paper, we explore this proposition by regressing the change in capital requirements on 23 bank-level variables that regulators had access to at the time of the decision. This exercise suggests that balance sheet variables explain only about a third of the total variation in capital requirement changes. The residuals from this regression will be orthogonal to balance sheet variables by definition. When we use them as an alternative capital requirement measure, instead of the actual changes in capital requirements, we find very similar effects to the baseline model across a number of specifications.

Ours is not the only study that examines the impact of prudential regulations on real economic activity with firm-level data. Jimenez et al. (2015) provide evidence for the impact of dynamic loan provisioning, a macroprudential instrument, on lending growth and employment outcomes with a detailed loan-level dataset on loans granted and applied for by firms operating in Spain. They find that in good times, 2001Q2-2008Q1, although credit committed declines, there is no change in credit available to firms, total assets or employment. They do find some negative effect of macroprudential policy on employment growth and firm survival for the borrowing firms, but only in bad times (2008-2012). Compared to Jimenez et al. (2015), we only analyse capital requirement changes in good times (1998-2006) and we still find negative effects on asset growth, but only in the first two years of a new bank-firm relationships. Brun et al (2013) use credit-registry data from France to examine the impact of the introduction of Basel II in 2007-2008 on French firms and banks. In comparison, all of our regulatory changes occurred before the global financial crisis and the introduction of Basel II, which means that we can confidently say that any effect we find is due to regulatory changes.

The advantage of the time period we analyse is that it is easier to interpret changes in capital requirements as what they are, in the absence of any other major shocks to the banking system. However, we acknowledge the fact that we are examining the impact of *micro-prudential*, rather than *macro-prudential*, policy. Furthermore, with 100 changes for 67 banks over a period of 9 years, capital requirements changes were very infrequent. The results in our paper are therefore perhaps more informative about the costs associated with the permanent increases in capital requirements experienced by the banking system today.

The remainder of the paper is structured as follows: Section 2 describes the UK regulatory regime and the data. Section 3 describes the empirical approach for each of the proposed hypotheses, presents the results and examines them for robustness. Section 4 concludes.

2. UK capital requirement regulation and data

2.1 Bank-level data

After the introduction of Basel I in 1988, most countries set bank capital requirements at a fixed 8% of RWA for all banks. However, this did not happen in the UK, where regulators adopted bank-specific capital requirements. These requirements were subject to review either on an on-going basis or every 18-36 month. This regulatory regime was first implemented by the Bank of England, with the Financial Services Authority (FSA) taking over in 1997. The FSA based regulatory decisions for banks on a system of guidelines called ARROW (Advanced Risk Responsive Operating frameWork), which covers a wide array of criteria related to operational, management, legal and interest rate risks and many others.

The ARROW approach was risk-based, but anecdotal evidence suggests that there was greater emphasis on operational (Pillar II), as oppose to balance sheet and credit risk (Pillar I). For example, in his high-level review into UK financial regulation prior to the financial crisis of 2008, lord Turner, the chief executive of the FSA, concluded that: “Risk Mitigation Programs set out after

ARROW reviews therefore tended to focus more on *organisation structures, systems and reporting procedures, than on overall risks in business models*" (Turner, 2009). Similarly, the inquiry into the failure of the British bank Northern Rock concluded that "under ARROW I there was *no requirement on supervisory teams to include any developed financial analysis* in the material provided to ARROW Panels" (FSA, 2008). Moreover, in the same report it was recognized that '*the FSA is short of expertise in some fundamental areas, notably prudential banking experience and financial data analysis*' (FSA, 2008).

Based on this anecdotal evidence, Aiyar et al (2014a,b,c) argue that capital requirement changes are mostly based on qualitative, rather quantitative analysis and hence they are plausibly uncorrelated with respect to banks' balance sheet risks. In this paper, we test whether balance sheet characteristics available to supervisors at the time the decision was made can predict capital requirement changes. We find that this is partly the case, but only for about a third of the variation in capital requirement changes. When we use the residuals from this regression, which are orthogonal to balance sheet conditions by definition, we find very similar baseline results across a range of specifications.

The Bank of England has kindly made these regulatory capital requirements data available. We collect data on a total of 67 regulated banks' lending to UK Private Non-Financial Companies (PNFCs henceforth). Our study covers the time period from 1998 to 2006. We decide the end our analysis in 2006 for two reasons. First, the data after 2006 may have been affected by the start of the UK banking crisis associated with failure of the bank Northern Rock in 2007Q3. Second, after 2008Q1, UK regulators relied on the risk-weights associated with Basel II. Unlike the Basel I risk weights, which simply assigned a weight of 100% to PNFC loans, risk weights under Basel II can be calculated using banks' Internal Risk Based (IRB) models. This additional regulatory margin would add a further layer of complexity to our analysis.

Regulated institutions were affected by 100 capital requirement changes during this time, all of which are shown in Figure 1, with summary statistics provided in Table 2. All of the other lender level balance sheet data were provided by the Bank of England's Statistics and Regulatory Data Division. The control variables we derive from these data are described in greater detail in Table 1, with the corresponding summary statistics provided in Table 2.

2.2. Firm-level data

Firm level data come from the *Bureau Van Dijk Financial Analysis Made Easy* (BvD FAME) database, based on companies' filings with Companies House, the UK's firm registry. The key aspect of this dataset is that it contains the names of the banks each firm has a secured loan with. Banks are legally required to register these loans with Companies House twenty-one days after the loan has been created. If the bank fails to do so, it would not be able to seize the collateral in case the company became insolvent. Indeed, the Bank of England surveyed one of the UK's 5 largest lenders in 2013 to examine whether these data actually reflect bank-firm relationships. This was the case for 99.8% of the firm-bank relationships in this dataset, which suggest a high degree of accuracy. There is are some important dimensions in which the data are different from the Credit Registry data used in other work (Jimenez et al. (2012, 2014, 2015), Brun et al. (2013), Gobbi and Sette (2012) among others); in particular, they do not contain information on the amount of credit provided by each bank. Therefore, we cannot use the firm×time fixed-effects identification pioneered by Khwaja and Mian (2008), as we do not have data on the loan amounts each bank provides to each firm.[2] However, the most important feature of the data is that it allows us to link the banks in our sample to individual firms. Moreover it does so at a specific point of time, which means that we can calculate the length of the bank-firm relationship based on actual transactions rather than on survey data (Petersen and Rajan (1994)). Finally, in order to examine our results for

[2] Most of the companies in our sample (88%) have single bank relationship anyways.

robustness, the firm-bank panel nature of the data also allows us to include bank-time effects, which fully control for endogeneity bias at the bank level.

There is a total of 331,000 PNFCs with charges registered in BvD FAME (June 2007 version) and financial data for 1998 to 2006. We match a total of 252,992 firms to 67 banks with available capital requirements data. Most of the firms in our sample are *small*: 92% have assets below $2.8mil, the official threshold for "small" companies as defined by Companies House. The large presence of small firms, that do not need to report full balance sheet, generates many missing items. Indeed, other than age and length of the relationship, Total Assets is the most highly populated balance sheet variable, while Turnover and Employees are under-represented (Table 2). We also have a good coverage of current liabilities - which include short-term debt, trade credit and taxes - and of credit scores, as these are calculated by an external credit rating agency on the basis of both financial and non-financial information (directors' and shareholders' history, County Court Judgements). Importantly information on the sector (4 digit *Standard Industry Classification (SIC)* code) and the full postcode are available for all firms, including small ones. Single-bank relationship is dominant (88%), which is not surprising in light of the fact that most of the firms in our sample are small. However, even if only 12% of firms have a banking relationship with multiple institutions, given our large sample size we still have 26,800 firms with two banks. Another characteristic of the UK banking system is that it is very concentrated: the top 5 banks provide credit to 91% of firms in our sample. Regarding the distribution of firms by sector, we find that the Commercial Real Estate (CRE) sector is the most dominant (37%) followed by Wholesale and Retail Trade (17%), Construction (13%) and Manufacturing (12%). Together these sectors comprise 79% of the companies in our sample.

In conclusion, our dataset contains 252,000 UK PNFC firms, borrowing from 67 different banks with capital requirement changes between 1998-2006. Most firms are *small*, they borrow from a *single bank*, especially one of the big 5, and they are concentrated in the CRE sector. We know both the age of the firm and the length of the relationship with each bank. We have good coverage of firms' credit scores and share of current liabilities over total assets, but not of turnover, profits or number of employees. Finally, we know the full 4digit SIC code and postcode area where these firms operate.

3. Empirical approach and results

3.1 Empirical strategy

For capital requirements to affect the real economy, through the impact on loan supply, three conditions need to be satisfied: i) Bank equity needs to be more expensive than bank debt; ii) Capital requirements need to be a binding constraint on a bank's choice of capital and iii) borrowers need to have limited access to alternative sources of finance other than lending from affected banks. The first condition implies a failure of the Miller-Modigliani (1958) theorem for banks. Economic theory provides good reasons for why condition i) should be satisfied, such as asymmetric information (Myers and Majluf (1984)) and the difference in tax treatment between debt and equity. While we will assume that condition i) holds from theory, we can directly test whether conditions ii) and iii) are present in the data.

Regarding condition ii), we sort banks by their capital buffers (*i.e.* the difference between the actual capital ratio and the capital requirement). Presumably, banks with tight capital buffers find the capital requirement to be binding and hence they will be more affected by capital requirement changes. A cursory examination of our data (Figure 2) suggests that this indeed case: the average capital requirement (*KR*) and average capital ratios co-move almost one-to-one for banks in the bottom quartile of the capital buffer distribution. Moreover several empirical studies, namely Alfon et al (2005) and Bridges et al (2014), demonstrate that UK capital requirements were a binding constraint on UK bank's capital choices with a regression framework.

Condition iii) has testable implications too. For example, if firms can borrow from branches of foreign banks, then they will be less affected by changes in capital requirements at UK-resident banks. In fact, as long foreign branches are not incorporated in a subsidiary, they are not subject to UK capital regulation and they can offset the fall in lending from UK banks (Aiyar, Calomiris and Wieladek (2014b). More in general, if firms can access capital markets, they will not be affected by changes in bank lending. We have sectoral (1 digit SIC) level information on the lending by foreign branches and capital markets borrowing that we will explore in more detail in section 3.6. In short, we find evidence for credit substitution from foreign branches, but not from capital markets.

If conditions i)-iii) are satisfied then we expect a negative impact on borrowers following a rise in capital requirements at their main relationship bank. Thus, ideally and intuitively, we would test this hypothesis with the following regression:

$$\Delta \, ln \, Y_{i,t} = \delta_1 \Delta KR_{j,t} + +\varphi FC_{i,j,t} + \gamma BC_{j,t} + \alpha_i + T_{hkt} + e_{i,j,t}$$

where $\Delta \, ln \, Y_{i,t}$ is the change in the natural logarithm of total assets (or investment or current liabilities) of firm *i* that has an existing loan from bank *j* at time *t*. $\Delta KR_{j,t}$ is change in the minimum capital requirement ratio of bank *j* associated to firm *i* at time *t* [3]. $FC_{i,j,t}$ and $BC_{j,t}$ are vectors of firm and bank characteristics, all of which are listed in Table 1. α_i is a firm fixed effect to

[3] For firms with a single bank relationship (88% of the sample), we just use the $\Delta KR_{j,t}$ of the main relationship bank *j*. But for banks with multiple relationships, we take an average of $\Delta KR_{j,t}$ across all banks that lend to firm *i*

account for firm unobservable time-invariant characteristics.[4] T_{hkt} is a vector of sector-area year effects to account for unobservable geographical and sector differences, in particular for loan demand and unobservable characteristics. All standard errors are clustered at the firm level in each regression specification.

However, the estimated $\widehat{\delta_1}$ from equation (1) would not be significant if the effect of capital requirements was not linear but instead was dependent on the length of the bank-firm relationship. Economic theory suggests that this could be important: Bolton et al (2013) find that relationship banks attenuate negative shocks to individual firms during a crisis. Since the change in capital requirements should affect firms with short-relationships relatively more, we interact the change in capital requirements with a non-linear function of length. For example, we could use a log-interaction:

$$\Delta \ln Y_{i,t} = \alpha_i + \delta_1 \Delta KR_{j,t} + \delta_2 \Delta KR_{j,t} * \ln(L_{i,j,t}) + \mu \ln(L_{i,j,t}) + \varphi FC_{i,j,t} + \gamma BC_{j,t} + T_{hkt} + e_{i,j,t} \qquad (1)$$

where $L_{i,j,t}$ is the length of the relationship between firm *i* and bank *j* a time *t* measured in years. In this specification we expect $\widehat{\delta_1} < 0$ and $\widehat{\delta_2} > 0$, meaning that the initial negative effect of capital requirement changes on firms' asset growth is attenuated as the length of the bank-firm relationship increases. Alternatively and equivalently, we could use the following:

$$\Delta \ln Y_{i,t} = \alpha_i + \delta_1 \Delta KR_{j,t} + \delta_2 \Delta KR_{j,t} * \frac{1}{1+L_{i,j,t}} + \mu \frac{1}{1+L_{i,j,t}} + \varphi FC_{i,j,t} + \gamma BC_{j,t} + T_{hkt} + e_{i,j,t} \qquad (2)$$

This would imply a $\widehat{\delta_1} > 0$ and $\widehat{\delta_2} < 0$. The specific convex and decreasing functional form for the length $(1/(1 + L_{i,j,t}))$ has the same property of the log-specification allowing for the effect of capital requirements changes to be

[4] The nature of our data does not allow for a firm×time fixed-effect a' la Khwaja and Mian (2008)

largest in the first year of a new bank-firm relationship ($L_{\mathrm{i,j,t}} = 0$) and then quickly decline over time. We choose this specific functional form so we can draw inference of the negative impact of capital requirements using $\widehat{\delta_2}$ and experiment with different type of fixed-effects, such as *bank-year* effects, that absorb the main effect δ_1. However, as Table 3 shows, choosing the log-specification or $\frac{1}{1+L_{i,j,t}}$ is identical in terms of estimated magnitudes.

In this study we aim to identify the loan *supply* effect of changes in capital requirements, and hence it is crucial to control for loan *demand*. To the extent that loan demand varies over time and across geographical boundaries, we can fully control for demand with *sector-area-year* fixed-effects. Information on the sector and location of the firm in our sample is very detailed: there is a total of 400 4-digit sectors and 2,757 full postcodes which we group in 122 postcode areas. Importantly, our matched firm-bank-year panel also allows us to use *bank-year* effects to control for any unobserved, time-varying omitted variable at the bank level. Going even further, we can construct *bank-sector-area-year* effects, to ease concerns that capital requirement changes are correlated with the credit portfolio of a specific bank. Indeed, with *bank-sector-area-year* effects we're fully controlling for each bank-borrower type pair, where the borrower type is identified by the sector and area where the firms operate.

3.2 Results

Table 3 presents estimates of equations (1)-(2) for the growth rate of total assets. All specifications include firm fixed effects and either *year* or $sector \times area \times year$ fixed-effects. In column (1) we show that the direct effect of capital requirement changes on firms' total assets is not significant on its own. In column (2), where we interact with $ln(L_{i,j,t})$, the coefficient on $\Delta KR_{j,t}$ is negative and it implies that for a 1 percentage point rise in capital requirements, the growth rate of assets declines by 2.5% in the first year of the relationship.

This effect is then attenuated for firms with longer relationships, as the coefficient on the interaction term $\Delta KR_{j,t} * ln\left(L_{i,j,t}\right)$ is positive. In column (3) we explore the alternative specification using $1/(1 + L_{i,j,t})$ interaction. The coefficient on $\Delta KR_{j,t}$ is positive, but the interaction term is negative. It implies that following a 1 percent rise in the capital requirement of bank j, firms *i's* asset growth declines by -2.6% (-0.034+0.08) in the first year of bank-firm relationship. This is very similar to the estimate obtained with the log-specification. Again this effect becomes weaker as the length of the relationship increases ($\frac{1}{1+L_{i,j,t}}$ is a decreasing function of length). This is consistent with a "positive" view of relationship lending whereby the affected bank does not cut lending to its long-term customers, but rather offer worse credit conditions to new borrowers. The coefficients barely change when the year effect (column (3)) is replaced with a more highly disaggregated *sector*×*area*×*year* effect (column (4)).

The regressions in columns (2)-(4) do not contain firm controls. In column (5) we therefore control for firms lagged characteristics: credit ratings, the share in current liabilities over total assets (as a proxy for short-term debt exposure) and the age of the firm.[5] The coefficient on the interaction term actually increases in absolute value, implying a decrease of 6.9% for any 1% increase in capital requirements in the first year of the relationship. Figure 3 plots the partial effect of a change in $\Delta KR_{j,t}$ on the growth rate of total assets ($\delta_1 + \delta_2 \times 1/(1 + L_{i,j,t})$) for the estimates in column (5). The negative effect of a 1 percent increase in capital requirements is greatest during the first year and then dissipates quickly over time, with an effect that is not significantly different from zero by the time 3 years have passed from the beginning of the relationship. Note that the smooth shape of the function is given by the convex

[5] Note that since the length of the relationship and the age of the firm are collinear with the firm fixed-effect (they both deterministically increase by one every year) we do not control for age as a continuous variable, but rather with dummies defined by quartiles of age.

function chosen for length ($\frac{1}{1+L_{i,j,t}}$), but this is borne out in the data too. A non-parametric regression, interacting $\Delta KR_{j,t}$ with 15 dummies, one for each year of length, yields a broadly similar shape (see appendix C), although the significance of the effect is now somewhat more dependent on the type of fixed-effects used. Next, we explore the robustness of our results to a large battery of sample selection, model and exogeneity assumptions about capital requirements in Table 4.

Our results hold if we change the dependent variable to investment, *i.e.* the growth rate of tangibles normalized by lagged total assets. This is important because it means that we can say with confidence that capital requirements have real, tangible effects on SME firms that borrow from the bank the first time. The concurrent decline in current liabilities also indicates that the decline in total assets is driven by a fall in short-term debt, such as bank debt. The interpretation of equation (2) hinges on two important econometric assumptions. First, we interpret $L_{i,j,t}$ as the length of the bank-firm relationship. But this could just reflect the age of the firm. In that case our regression estimates would imply that older, perhaps safer, firms are less affected by capital requirement changes. We explore this in the third row of Table 4 by replacing $L_{i,j,t}$ with age in our baseline regression. The results are not statistically significant anymore. This supports our interpretation of $L_{i,j,t}$ as the length of the firm-bank relationship. Second, we assume that changes in capital requirements can affect the asset growth of the borrowing firm, even after the relationship has been established ($\Delta KR_{j,t}$ can be different from zero in any year of the bank-firm relationship). However, we do not observe re-financing or changes in loan terms and firms could be taking out a single loan with fixed terms. To test for this, we could fix the change in capital requirements at its value in the first period of the relationship ($\Delta\overline{KR}_j$). These results, shown in row 4 of Table 4, are very similar to the baseline model. In row 5 we show that the results also hold for those loans for which we have a maturity date. This is important because the results may not be due to relationship lending but to a more mechanical reason: firms can repay their loans over time, and this would also decrease the average impact. However this does not seem to be the case.

A separate econometric issue is sample selection among both banks and firms. Table 2 suggests that our sample is dominated by small firms: the median firm has total assets of £350,000. With very small firms there is the risk that our sample might contain entities which exist purely on paper for tax purposes (*shell companies*). To explore if this is an issue, we exclude firms in the bottom half (£350,000) and 3rd quartile (£914,000) of the distribution in rows (6) and (7) of Table 4. To explore whether ownership structure matters, we estimate the base-line regression separately for firms where either more or less than 50% belongs to the same owner in the following two rows ((8) and (9)). The results are robust. Finally, 91% of the firms in the sample have relationships with 5 large UK banks. The remaining 9% have relationships with 62 different banks. In rows (10) and (11) we re-estimate the main model excluding either all the large banks or the small banks[6]. Our main result is robust to all of these perturbations, if anything borrowers of small banks are more affected.

In row (12) we replace the *sector*×*area*×*year*,with *bank*×*year* effects. The regression estimate on $\Delta KR_{j,t} * \frac{1}{1+L_{i,j,t}}$ is -.051, which is very similar to the base-line regression. Rows (13)-(15) take this even further by allowing the bank-year effects to vary with the sector (*bank*×*sector*×*year*) or area (*bank*×*area*×*year*) where the bank is lending or both simultaneously (*bank*×*sector*×*area*×*year)*. The results are remarkably stable to the inclusion of all these fixed-effects. This is especially comforting for us because it means that an institution's credit portfolio, as measured by its exposure to borrowers in a specific sector and area, is not correlated with changes in capital requirements.

[6] In unreported results, we also drop each of the large banks one at a time and the results still hold.

Overall this suggests that omitted variable bias at the bank-balance sheet level, and hence endogeneity from that source, does not seem to be a significant issue, consistent with our main identification assumption of an exogenous change in capital requirements with respect to credit conditions.

Finally, the main identification assumption in this paper, which we discussed extensively in section 2 is that changes in capital requirements were not determined by the quality of individual banks balance sheets. Although there is anecdotal evidence to support this assumption, it is possible that it is invalid. We re-examine our assumption in rows (16)-(17). For this purpose, we collect 23 balance sheet variables that supervisors could have taken into account in their regulatory decisions. We then use single, multiple and Bayesian Model Averaging regression models to identify the most important predictors of capital requirement changes. Please see appendix A for more details. We find that balance sheet characteristics can at most explain up to 36% of the variation in capital requirement changes. This suggests that the majority of capital requirement changes are due to non-balance sheet risk, in line with our initial assumption. We therefore use the residuals from these regressions as two alternative measures of $\Delta KR_{j,t}$, called ΔKR_Exog1 and ΔKR_Exog2. Rows (16) - (17) show that results with these 'more' exogenous measures of changes in capital requirements are remarkably similar to the base-line results. The results are robust to all bank-year fixed effects perturbation (not shown).

Overall Table 4 suggests that the results obtained with the base-line model are robust to sample selection issues at firm and bank level, more restrictive econometric modelling choices, omitted variables bias and exogeneity assumptions about $\Delta KR_{j,t}$.

3.3 Interaction with Bank and Firm Characteristics

Bank characteristics may affect the adjustment to changes in capital requirements. Banks with a greater fraction of retail deposit funding, which is subject to deposit insurance, will find equity relatively more expensive than debt and hence may adjust lending to a greater extent. Those with a lot of liquid assets can sell them for a profit and hence grow capital back through retained earnings. Changes to capital requirements should also affect highly-leveraged banks relatively more. While banks with high levels of capital can always choose to have a smaller capital buffer in response to a higher capital requirement, it is unlikely that this would be an option for banks whose capital buffer is already tight. Indeed, Figure 1 suggests that capital choices of banks in the bottom size quartile of capital buffers co-move almost contemporaneously with requirements, unlike those in the top quartile. Finally, banks with a large trading book, that has lower average risk-weights then the banking book, should be less affected by capital requirement changes.

We examine all of these hypotheses in Table 5, by interacting $\Delta KR_{j,t} * 1/(1 + L_{i,j,t})$ with each of these variables either linearly or with two dummies for top and bottom quartile. We report the marginal effects for the high and low category in the last two columns. This exercise suggests that *only the capital buffer*, both as a linear and non-linear interaction, is a statistically significant variable that affects the transmission of capital requirements: banks with tight capital buffers transmit this shock to a much greater extent. With the linear interaction, for any 1% increase in the buffer, the effect on new borrowers is attenuated by 1.4%. With the non-linear interaction, the results are similar. Note that the large magnitude of the effect for banks with small buffers (-19%) depends on the presence of the more disaggregated sector-area-year fixed-effects; with year fixed-effects only (not shown) the effect is more moderate, around -10%.

Firm characteristics may also affect the way in which a firm reacts to a loan supply contraction. Firms which are more debt reliant should be affected to a greater extent. Older firms are less likely to be affected by asymmetric information and could be affected less. Finally, riskier firms may also adjust in a different way. These regressions, shown in the lower panel of Table 5, do not suggest a significant degree of variation by individual firm characteristics, as opposed to the strong results by bank characteristics. When we split the effect by sector, the results suggest that changes in capital requirements have the biggest impact in the commercial real estate (CRE) sector, which is the most leveraged sector. This is consistent with the evidence in Bridges et al. (2014), who also find that lending to this sector shrinks the most in response to higher capital requirements.

3.4 Monetary policy

The failure of the Miller and Modigliani (1958) theorem for banks has also important implications for the transmission of monetary policy. If banks cannot easily substitute between insured and uninsured funding, they will have adjust their balance sheet in response to monetary policy. Kashyap and Stein (2000) provide empirical evidence on this for the US. They show that only small banks are affected by monetary policy, since it is easier for large banks to raise uninsured debt. We test whether this is the case for the UK too.

To explore all of these questions, we need a suitable measure of UK monetary policy. Unlike for the United States (Romer and Romer (2004)), there is no commonly accepted narrative measure of UK monetary policy shocks.[7] We therefore constructed our own measure of exogenous monetary policy shocks in this paper. Clarida, Gali and Gertler (2000) and Bernanke and Boivin (2003) show empirically that the Federal Reserve interest rate behaviour can be best characterised as a response to expected inflation and output growth. Similarly, during our time period of interest, the UK's Monetary Policy Committee objective was to maintain inflation close to target, while minimising output volatility, at the two year horizon. In line with previous work for the US,

[7] Cloyne and Huertgen (2014) employ this type of approach following Romer and Romer (2004) for the UK, although for a different sample period and focusing on the macroeconomic effects of monetary policy. At the time of writing this series was not yet ready to be shared publicly.

we estimate Taylor rule coefficients using the Bank of England's official forecasts of CPI inflation and real GDP growth two years ahead. This yields Taylor rule coefficients of 1.5 and 1, respectively. Yet agents form an expectation of the forecast announcement and may have already reacted to the monetary policy decision. To measure ex-ante expectations we use the mean of survey of professional forecasters. Subtracting the expectations for the forecast from the announced forecast in that time period, yields CPI inflation and real GDP growth forecast surprises. We then apply the estimated Taylor rule coefficients to these two surprises to construct our proposed measure of monetary policy shocks (see appendix B for more details).

From an econometric modelling perspective, we assume that monetary policy affects asset growth of the borrowing firms exactly as changes in capital requirements. That is, we again assume that firms will be less affected by monetary policy changes as the bank-firm relationship becomes longer over time. Given the aggregate nature of monetary policy, the main effect of monetary policy shocks will be absorbed by the time fixed-effects, so only the interaction with the function of length will show up in the regressions.

Table 6 explores the impact of monetary policy on asset growth within our econometric framework. Rows (1) – (2) show that monetary policy has an independent negative effect on individual firm's asset growth, with both sector-area-year and bank-year fixed-effects. These firm-level multipliers are similar in magnitude to those found in Aiyar et al. (2016) for bank lending to PNFC firms. In terms of the macro impact of monetary policy, since the fraction of new relationships is about 20% of total relationships each year, it would give an effect on aggregate investment of about 0.8-1.38% for any 1% rise in the bank rate. We then split the sample between large and small banks in rows (3)-(6). We define a *large bank* as one of the top 6 UK banks, while a *small bank* is any of the remaining 61 banks in the sample. Our results are consistent with the literature: monetary policy has a much smaller effect on firms that borrow from large banks. With bank year effects, the impact on large bank borrowers is not statistically significant anymore.

Next, we explore interactions with firm credit risk in rows (7) and (8). These suggests that monetary policy has a much bigger impact on the riskiest firms, which is consistent with the *risk-taking channel of monetary policy*. Dell'Arricia et al (2015) and Jimenez et al. (2014) find similar evidence for US and Spanish banks, respectively.We then re-estimate the model for each sector separately in rows (9) – (13). This suggests that monetary policy mostly impacts firms in the commercial real estate sector (CRE), like capital requirements do: this is the most leveraged sector of the economy, hence it is the most likely to respond to policy changes. The results are also robust to bank-year effects (not shown).

3.5 The Interaction of Monetary Policy and Capital Requirements

A debated issue is whether monetary and capital requirement policy should be co-ordinated. Clearly if each instrument has one target, and the effects of both instruments are completely orthogonal, no co-ordination is necessary. In that case, monetary policy would only focus on price stability, while capital requirement policy would only address financial stability. However, if one instrument affects the transmission of the other, then this will need to be taken into account. In this section we study whether these two instruments interact with each other. The UK experience between 1998 and 2006 is helpful in this respect, as the FSA and Bank of England were setting these instruments independently[8].

[8] The UK had an inflation-targeting monetary policy at that time. The analysis and debate of UK monetary policy issues were published in the Inflation Report. The word 'capital requirement' never appears.

Economic theory suggests that these two instruments could affect the transmission of each other, but the direction of the effect is unclear. Van den Heuvel (2002, 2005) proposes a bank capital channel of monetary policy. He shows that the two may reinforce each other, since an unexpected monetary policy contraction can lead to a smaller capital buffer, as a result of realised interest rate risk. Du and Miles (2015) argue that the two are imperfect substitutes, implying that optimal level of the central bank policy rate falls as prudential capital requirements are tightened. Angelini, Neri and Panetta (2014) discuss the need for cooperation between the two, especially in response to financial shocks. Despite the interest of the economic theory literature, empirical work that attempts to test these different transmission mechanisms is still scarce. Aiyar, Calomiris and Wieladek (2016) is one of the first studies to undertake this task with UK bank-level balance sheet data. Across a large number of different specifications, they do not find any statistical evidence that these two tools reinforce each other.

We introduce our measure of monetary policy and capital requirements jointly in Table 7. Column (1) shows that once monetary policy is included, a 100 basis points rise in monetary policy ($MPshock_t$) leads to an asset growth contraction of about 6.89%, roughly the same magnitude as a rise from capital requirements. Importantly, capital requirement changes still have an independent negative effect of a similar magnitude as before, even after controlling for monetary policy shocks. Column (2) adds the interactions between the monetary policy and capital requirements, together with the function of length with *year fixed-effects*. Note that both $\Delta KR_{i,t} \times MPshock_t$ and $\Delta KR_{i,t} \times MPshock_t \times \frac{1}{1+L_{i,j,t}}$ have a significant effect on the growth rate of assets, suggesting that using both at the same time would have an additional negative interaction for firms with short relationships. However the effect is not robust to the use of other fixed-effects, such as *bank*-year in column (3) and *sector*×*area*×*year* in column (4). This suggests that, at first sight, there is no consistent interaction between the two, confirming the results in Aiyar, Calomiris and Wieladek (2016) and contrary to the bank capital channel in Van den Heuvel (2002). The results are robust to the alternative measures of monetary policy described in Appendix C (not shown, available upon request).

In Table 8, we explore whether the interaction of capital requirements and monetary policy depends on the sign of monetary policy and on the size of banks. To reduce the number of interactions and have a more intuitive interpretation of the results, here we are only interacting with the monetary policy stance as defined by the dummy $TIGHT_t$, equal to one in case of tightening, rather than the quantitative monetary policy surprise series as before. The results clearly indicate, either with sector-area or bank-year fixed effects, that only small banks are negatively affected by changes in capital requirements during a monetary policy tightening. The effects are large and they imply that, for new borrowers of small banks, a 1% increase in capital requirements reduces asset growth by 13% or 9.7%, depending on the type of fixed-effects, following a monetary policy tightening. The result does not hold for large banks, for which there is no significant interaction between capital requirements and tight monetary policy. A possible explanation for this result is that small banks are more sensitive to interest rate risk. In fact, Landier et al. (2015) show that US banks are significantly exposed to interest rate risk and that lending by the most exposed banks is more sensitive to monetary policy, especially for small and unhedged institutions.

In conclusion, monetary policy has an independent negative effect on individual firm asset growth. Our results suggest that the sectors which react to monetary policy, are also the ones most affected by changes in capital requirements. We also find a strong additional negative interaction with capital requirements for small banks, following a monetary policy tightening. The result is intuitive insofar as small banks' capital buffers are more sensitive to interest rate risk than those of large banks and the smaller the buffer, the larger the impact of capital requirement changes, as shown in Table 5.

3.6 Does credit substitution affect the real impact of changes to capital requirements?

So far we have examined to which extent changes in capital requirements on individual banks affect the asset growth rate of the borrowing firms within a partial equilibrium framework. But in general equilibrium, alternative sources of credit from branches of foreign banks, which are not affected by capital requirement changes, or from capital markets, may offset these effects.

In Table 9, we interact the fraction of either foreign branch lending (*BLnonreg*) or capital markets finance (equity + bond issuance, *Nonbank*) over the lending done by all UK-resident bank (*BLreg*) at the 1digit sector level with our main coefficients of interests. The bottom panel of Table 9 shows the partial derivative of total asset growth with respect to changes in capital requirements for a zero or one standard deviation increase in either *BLnonreg/BLreg* or *Nonbank/BLreg*. We can see that for firms in sectors with a high dependence on lending by foreign branches (*i.e.* one standard deviation increase in the ratio of foreign branches' lending over regulated lending) the effects of capital requirements is reduced by 3% (column (1)). Increasing capital markets finance over regulated lending (columns (2)) has no significant effect instead. These regression results overall confirm the previous findings in Aiyar, Calomiris and Wieladek (2014b) that credit substitution from foreign branches, in these data, is substantially stronger than that from capital markets.

However, our data allow for a much more direct and powerful test of the credit substitution hypothesis. If financial entities, which were not affected by changes in capital requirements, truly are a source of credit substitution, then firms with multiple bank relationships should not be affected by capital requirement changes to only one of their relationship banks. On the other hand, we expect monetary policy to affect all firms, regardless of the number of banking relationships. This is consistent with the idea that monetary policy is an aggregate policy instrument. Note that to run this test we need to somewhat modify our baseline specification: $\Delta KR_{j,t}$ is in fact the average of the capital requirement changes of all banks related to one particular firm. Thus, we will allow the capital requirement of each bank to affect the asset growth of the related firm individually, rather than as an average. We interact both capital requirement changes and monetary policy shocks with $bank2dummy$, that takes value one if the firm has two relationship banks and 0 otherwise. In that case we are interacting with the capital requirement of the second bank.

The results from this exercise are presented in Table 10, across three alternative measures of monetary policy, one per column. First of all, the coefficients on $\Delta KR_{i,t} \times 1/(1 + L_{i,t})$ and $MP_t \times 1/(1 + L_{i,t})$ are significant and negative on their own (*i.e.* not only as an interaction with $bank2dummy$) implying that *single-bank firms* are negatively affected by both capital requirements and monetary policy shocks at the beginning of the relationship. However the results are clearly different when we look at firms with two banks. Now, the total partial effect of a 1% change in capital requirements for firms with two banks is not statistically significant (see bottom panel in Table 10), as the interaction term with the $bank2dummy$ is positive (although not significant). Monetary policy on the other hand affects all firms equally, as the interaction coefficient with $bank2dummy$ is negative.

Thus estimated on the same sample, monetary policy affects all of the firms through the length of the relationship, regardless whether the firm is a single or multiple relationship bank. This is a novel result in the empirical literature and it carries important policy implications for the use of monetary versus prudential policy.

4. Conclusion

Following the global financial crisis of 2007-09, countries around the world are raising capital requirements to increase the resilience of the financial system to financial crises. But, to date, there is little evidence of how this affects the real economy. The UK's unique regulatory regime, where banks were subject to individual and time-varying capital requirements, together with a large firm-bank level database allows us to provide a first empirical examination of this important question. We also compare our effect to monetary policy and examine if credit substitution may offset some of these effects.

We find that a 1% increase in a bank's capital requirement or monetary policy leads to a decline in the asset growth rate of the borrowing firm of about 6.9% in the first year of new bank-firm relationship. SMEs borrowing from banks with tight capital buffers are more affected by the regulatory change. While prudential policy affect *single*-bank firms only, *i.e.* those that cannot easily find alternative sources of external finance, monetary policy shocks have a larger aggregate effect. There is also a powerful negative interaction between capital requirements and a tightening of monetary policy, but only for small banks, whose buffers are more likely to respond to interest rate risk. Since these interactions are only present for small banks, imperfect co-ordination of these policies may not necessarily result in large macroeconomic costs.

Our findings also have important policy implications. At present, capital requirements throughout the world are rising, as envisioned under Basel III. Our work suggests that this will lead to a temporary, but significant, contraction in investment. We also show that monetary policy only affects borrowers of small banks and hence cannot fully offset the total effect of capital requirement changes via the bank lending channel. Overall, this means that the transition to higher capital requirements, even when monetary policy is expansionary, will be costly, particularly in bank-based financial systems such as the Euro Area.

References

Aiyar, S, Calomiris, C and Wieladek, T (2014a), 'Does macro-pru leak? Evidence from a UK policy experiment,' *Journal of Money, Credit and Banking* 46(1), pages 181-214

— (2014b), 'Identifying Sources of Credit Substitution when Bank Capital Requirements are Varied', *Economic Policy* 29(77), pages 45-77

— with Hooley, J. and Korniyenko (2014c), 'The International Transmission of Bank Minimum Capital Requirements', *Journal of Financial Economics*, 113(3), pages 368-382.

— (2016), 'How does credit supply respond to monetary policy and bank minimum capital requirements?', *European Economic Review*, Vol.82, pp.142-165

Alfon, I, Argimón, I and Bascuñana-Ambrós, P (2005), 'How individual capital requirements affect capital ratios in UK banks and building societies,' *Working Paper 515,* Bank of Spain.

Angelini, P., Neri, S. and Panetta, F. (2014), 'The Interaction between Capital Requirements and Monetary Policy', *Journal of Money, Credit and Banking,* Vol. 46, No. 6

Bernanke, B and Blinder, A. (1988), 'Credit, Money and Aggregate Demand,' *American Economic Review P&P* 78, No.2, 435-439

Bernanke, B. and Boivin, J. (2003), 'Monetary Policy in a data-rich environment', *Journal of Monetary Economics*, Vol.50(3), pp.525-546

Bolton, P., Freixas, X., Gambacorta, L. and Mistrulli, P. (2013), 'Relationship and Transaction Lending in a Crisis', NBER WP 19467

Bridges, J, Gregory, D, Nielsen,M, Pezzini, S, Radia, A and Spaltro, M (2012), 'The Impact of Capital Requirements on Bank Lending,*' Bank of England WP 486.*

Brun, M., Fraisse, H. and Thesmar, D. (2013), 'The Real Effects of Bank Capital Requirements', *Débats économiques et financiers Banque de France*

Clarida, R., Galì, J. and Gertler, M. (2000), 'Monetary Policy Rules and Macroeconomics Stability: Evidence and Some Theory', *The Quarterly Journal of Economics,* Vol. 115(1), pp.147-180

Cloyne, J. and Hürtgen, P. (2014), 'The Macroeconomic Effects of Monetary Policy: a new Narrative Approach for the UK', *Bank of England WP 493*

Doppelhofer, G., Miller, R and Sala-i-Martin, X (2004), 'Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach', *American Economic Review,* 94(4): 813-35, September 2004.

Du, C. and Miles, D. (2015), 'Capital requirements, monetary policy and the fundamental problem of bank risk taking', *Working Paper*

Dell'Arricia, G., Laeven, L and Suarez, G (2015), 'Bank Leverage and Monetary Policy's Risk-taking Channel: Evidence from the United States', *IMF WP 13/143*

Fernandez, C., E. Ley, and M. Steel (2001). 'Model uncertainty in cross-country growth regressions', Journal of Applied Econometrics, vol. 16(5), pp. 563-576.

FSA (2001), 'Individual Capital Requirements'
— (2008), 'The supervision of Northern Rock: a lesson learned review'

Galati, G and R Moessner (2014), 'What Do we Know about the Effects of Macroprudential Policy?', *DNB Working Paper No. 440*

Jimenez, G,Ongena, S, Peydro, J and Saurina, J (2012), 'Credit Supply and Monetary Policy: Identifying the Bank Balance-Sheet Channel with Loan Applications', *American Economic Review,* August Vol.102, No.5, 2301-26
— (2014), 'Hazardous Times for Monetary Policy: What Do Twenty-Three Million Bank Loans Say about the Effects of Monetary Policy on Credit Risk-Taking?' *Econometrica* 82 463-505.
— (2015), 'Macroprudential Policy, Countercyclical Bank Capital Buffers and Credit Supply: Evidence from the Spanish Dynamic Provisioning Experiment,' *European Banking Center Discussion Paper.*

Kashyap, A. and Stein, J., (2000), 'What do a Million Observations on Banks Say about the Transmission of Monetary Policy?', *American Economic Review,* Vol.90, No.3, pp.407-428

Khwaja, A and Mian, A (2008), 'Tracing the effect of bank liquidity shocks: evidence from an emerging market', *American Economic Review,* Vol. 98, No.4, pages 1413A42.

Landier, A., Sraer, D. and Thesmar, D. (2015), 'Banks Exposure to Interest Rate Risk and the Transmission of Monetary Policy', NBER WP 18857

Miller, M and Modigliani, F (1958), 'The Cost of Capital, Corporation Finance and the Theory of Investment,' *American Economic Review,* Vol. 48, Pages 261-297.

Myers, S and Majluf, N (1984), 'Corporate financing and investment decisions when firms have information that investors do not have,' *Journal of Financial Economics,* Vol. 13, Pages 187-221.

Petersen, M. and Rajan, R. (1994), 'The Benefits of Lending Relationships: Evidence from Small Business Data', *Journal of Finance*. 49(1): 3-37.

Romer, C and Romer, D (2004), 'A New Measure of Monetary Shocks: Derivation and Implications'. *American Economic Review,* Vol.94, No.4, Pages 1055-1084

Turner, A (2009), 'The Turner Review: A regulatory response to the global banking crisis'

Van den Heuvel, S (2002), 'Does bank capital matter for monetary transmission?', Economic Policy Review, Federal Reserve Bank of New York, May, pages 259-265
— (2005), ',The Bank Capital Channel of Monetary Policy', unpublished manuscript available at URL http://repec.org/sed2006/up.31231.1139971981.pdf

Zellner, A (1986). 'On assessing prior distributions and Bayesian regression analysis with g-prior distribution' In: P.K. Goel & A. Zellner (Eds) *Bayesian Inference and Decision Techniques*, pp. 233-243 (Amsterdam, North Holland)

Figure 1: Number of Capital Requirement Changes

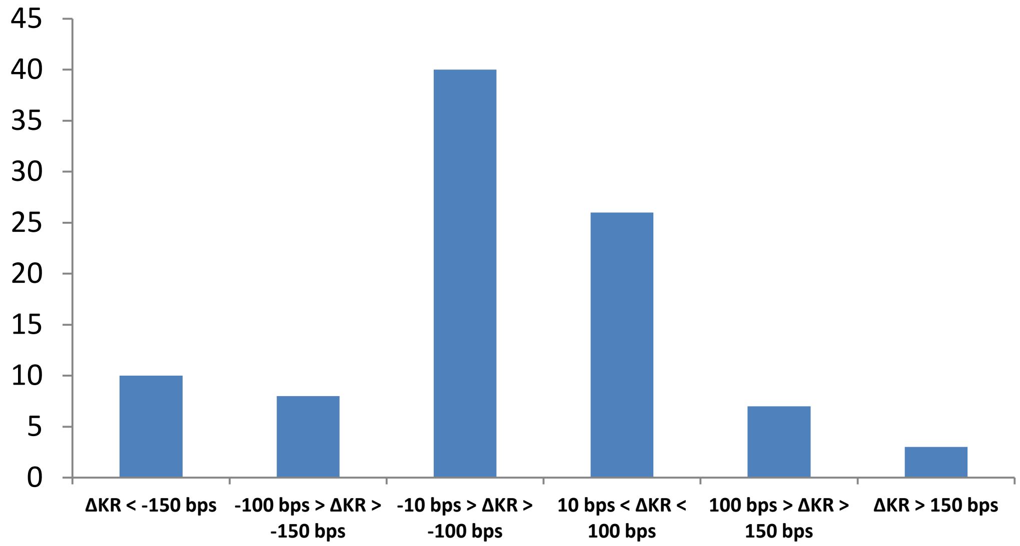
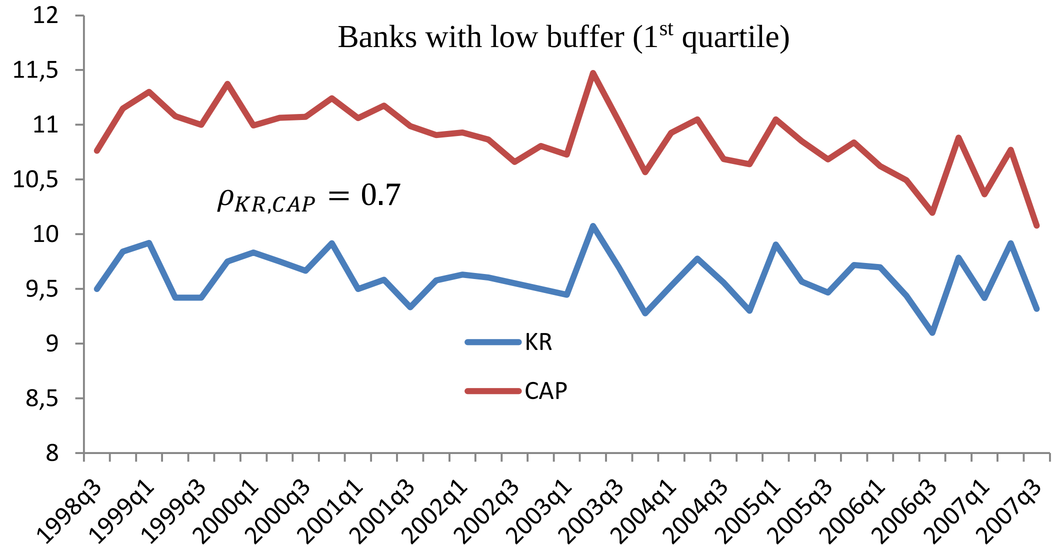
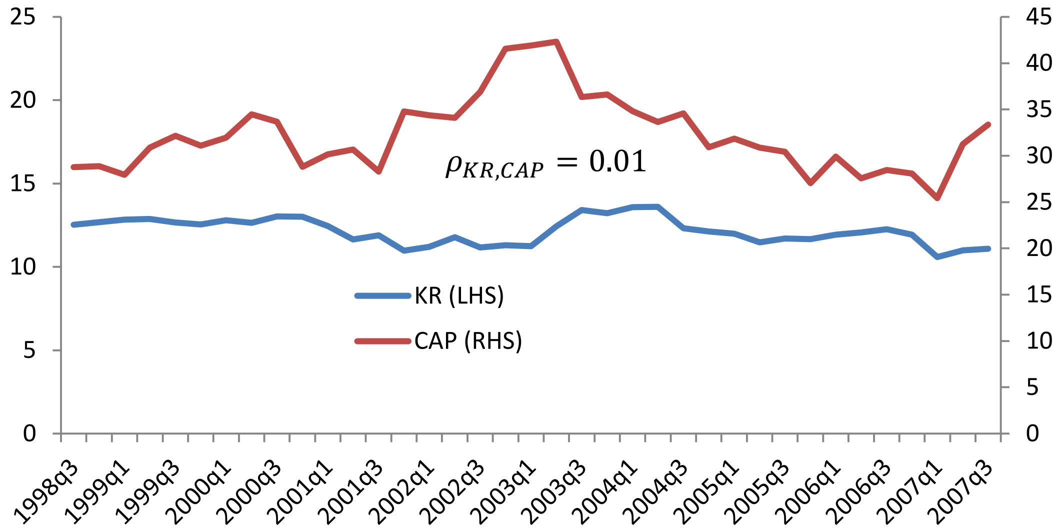


Figure 2: Capital Requirements and Capital Ratios by Bank Buffer

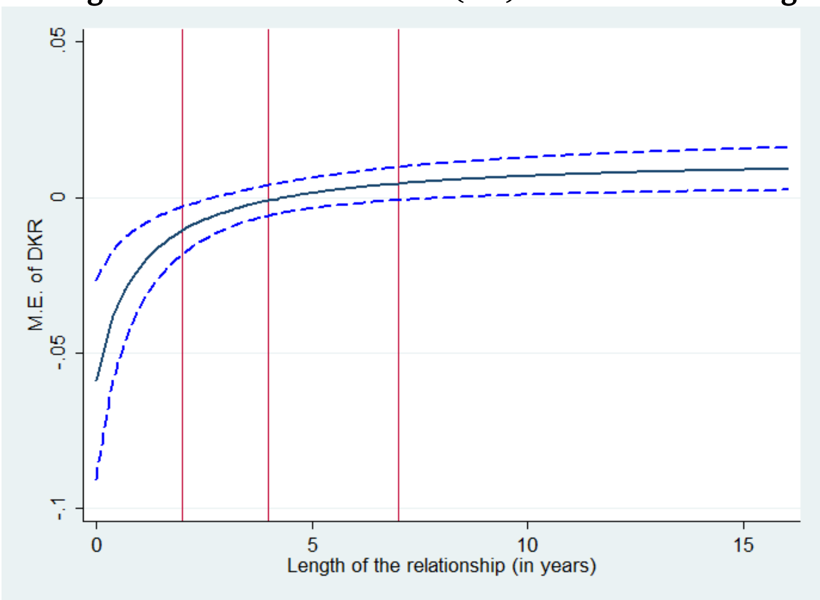


Banks with high buffer (4th quartile)



<u>Note</u>: This figure contains the average capital requirement (KR) and capital ratio (TotCapital/ RWA) for banks with low buffer (1st quartile) in the upper panel and high buffer (4th quartile) in the bottom panel. In the bottom panel the capital ratio (red line) is on the <u>right-hand-side scale</u>. Source: regulatory forms (BSD3) at a quarterly frequency

Figure 3: Marginal Effect of ΔKR on $\Delta ln(TA)$ as a function of length



<u>Note</u>: This figure contains the plot of the marginal effect of a change in capital requirement on the growth rate of assets for the baseline specification including lagged firm controls. The partial derivative is a function of length and the vertical red lines represent the 25th (2years), median (4) and 75th (7) percentiles of the distribution of the firm-bank relationship length in years. Dashed lines show the 95% confidence interval around the point estimate.

Table 1

Variable	Definition
Firm and bank-firm relationship data (BvD FAME)	
CredScore	From 0 (worst) to 100 (best). Calculated by CRIF Decision Solutions Ltd.
Currliab/TA	Curren Liabilities over Total Asset Ratio.Current liabilities include: Short Term Loans & Overdraft, Trade Creditors and Taxes & Dividends
Age	Years since date of incorporation
Length	Years since creation of the loan
Independence Index	From A (no shareholder with ≥ 25%) to D (one shareholder with ≥ 50%)
Bank level data (BSD3 and QFS forms)	
KR_t	Minimum ratio for capital-to-RWA for the banking book.
ΔKR_t	Yearly change in KR
$\Delta Woff_t$	Yearly change in writeoffs rate: nbpa550t/nhd510
Bank Size	Natural log of Bank Total Assets (BT40)
Bank Liquidity	Liquid (Cash+Govt.bonds) to Total Assets ratio: (BT21+ BT32D)/BT40
Core Funding	Retail Deposits to Total Assets ratio: (BT2H +BT3H)/BT40
Buffer	Actual Capital Ratio (nhd40/nhd510) minus KR
Sector level data on external finance	
BLreg	Regulated Lending: lending by UK resident banks
BLnonreg	Non-regulated Lending: lending by foreign branches
Nonbank	Non bank (equity and bond outstanding) external finance

Table 2: Summary Statistics

Variable	Observations	Mean	Std.	25th	50th	75th
Firm and bank-firm relationship data (firm-year panel BvD FAME)						
Total Assets(£mil.)	1,146,711	2.12	53.75	0.137	0.351	0.914
Δln(TA)	967,551	0.076	0.406	-0.072	0.029	0.204
Turnover (£mil.)	285,434	4.54	13.42	0.143	0.522	2.431
Employees (#heads)	125,453	146.5	1049.6	11	44	103
CredScore	1,107,154	50.2	22.60	35	48	64
Currliab/TA	1,139,230	0.63	0.553	0.307	0.547	0.809
Age	1,413,935	12.57	13.68	4	8	16
Length	1413944	4.82	3.922	2	4	7
Bank level data (bank-year panel)						
KR_t (%)	520	11.55	3.07	9	10	13
ΔKR_t (bps.)	520	-4.1	57.2	0	0	0
$\Delta Woff_t$ (bps.)	516	1.655	97.5	-3.972	0	6.365
Size (in £mil.)	520	32,590	89,367	710	4,104	15,100
Liquidity (bps)	520	161	271	1	43	220
Core Funding (%)	520	51.04	30.79	21.92	53.52	79.57
Buffer (%)	517	16.58	33.32	3.1	6.8	14.4
External Finance Dependence data (sector-year panel)						
BLnonreg/BLreg	126	0.52	0.65	0.04	0.26	1.18
Nonbank/BLreg	126	1.29	2.7	0.006	0.2	4.4

Table 3 – Capital Requirements and Firms' Growth Rate of Assets

	(1)	(2)	(3)	(4)	(5)
$\Delta KR_{i,t}$	0.008	-0.0252***	0.008***	0.007**	0.013***
	(0.065)	(0.008)	(0.00266)	(0.00368)	(0.00437)
$\ln(1+L_{i,t})$		-0.151***			
		(0.004)			
$\Delta KR_{i,t} \times \ln(1+L_{i,t})$		0.013***			
		(0.004)			
$1/(1+L_{i,t})$			0.42***	0.425***	0.459***
			(0.00411)	(0.00571)	(0.0113)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$			-0.0340***	-0.0352***	-0.0721***
			(0.00946)	(0.0130)	(0.0197)
$CredScore_{i,t-1}$					0.001***
					(4.6e-5)
$Currliab/TA_{i,t-1}$					0.130***
					(0.005)
Young					0.018***
					(0.002)
Old					0.003
					(0.003)
Firm Fixed Effects	X	X	X	X	X
Year Fixed Effects			X		
SIC4dig×Postcode ×Year Fixed Effects	X	X		X	X
Observations	985,124	968,012	969,052	968,012	871,423
N of firms	215,894	212,894	212,894	212,894	196,980
R squared	0.323	0.443	0.338	0.444	0.445

This table presents the results for the baseline regression. The dependent variable is the log difference of total assets by firm i between time t and t-1. All specifications include firm fixed-effects and either year fixed effects (column (3)) or SIC4dig*postcodearea*year fixed-effects (other columns). $\Delta KR_{i,t}$ is the change in capital requirements between year t and year t-1 for the bank lending to firm i (it is averaged over all banks lending to firm i at time t in case of multiple banks). $L_{i,t}$ is the length of the relationship between firm i and its banks, measured in years since the creation of the loan. $CredScore_{i,t}$ is the credit score of the firm, measured on a scale of 0 (worst risk) to 100 (no risk). $Currliab/TA_{i,t}$ is the ratio of Current Liabilities (short term debt, trade credit, taxes and dividends) over total assets. $Young, Old$ are dummies for the age of the firm, at the 25th and 75th percentiles (4 and 16 years old respectively). For statistical significance, we use the following convention throughout: *** p<0.01, ** p<0.05, * p<0.1. Firm-clustered standard errors are reported in parenthesis.

Table 4: Robustness of Baseline Results

Robustness Exercise	$\Delta KR_{i,t}$	$1/(1 + L_{i,t})$	$\Delta KR_{i,t}$ $\times 1/(1 + L_{i,t})$
Alternative Dependent Variables			
(1) Investment ($\Delta Tang/TA_{t-1}$)	0.0227*	1.056***	-0.120**
(2) Current Liabilities (*Δlog(Currliab)*)	0.0162**	0.408***	-0.0797***
Econometric Assumptions			
(3) Replace $L_{i,t}$ by firm age	0.00415	0.739***	-0.0430
(4) $\Delta\overline{KR}_i$		0.478***	-0.0715***
(5) Loans with maturity date	0.0167	0.311***	-0.105**
Sample Selection – Firms and Banks			
(6) Exclude firms bottom 50%	0.015***	0.502***	-0.093***
(7) Exclude firms bottom 75%	0.019**	0.504***	-0.116***
(8) Firms with > 50% single ownership	0.0146**	0.436***	-0.0654**
(9) Firms with < 50% single ownership	0.0151**	0.500***	-0.0835**
(10) Small banks only	0.025***	0.514***	-0.123***
(11) Large banks only	0.01*	0.45***	-0.055**
Endogeneity - Omitted Variable Bias			
(12) Bank-year effects	-0.0185*	0.471***	-0.0508***
(13) Bank-Sector-year effects	-0.0191*	0.465***	-0.0586***
(14) Bank-Area-year effects	-0.0144	0.467***	-0.0438***
(15) Bank-Sector-Area-year effects	-0.0320**	0.493***	-0.0590**
Endogeneity – ΔKR Exogeneity Assumption			
(16) ΔKR_EXOG1	0.00964**	0.462***	-0.0550***
(17) ΔKR _EXOG2	0.0132**	0.465***	-0.0772***

All specifications include lagged firm variables, firm fixed-effects and SIC4dig*postcodearea*year fixed-effects, unless otherwise stated. Standard errors are clustered at the firm level

Table 5: Interaction with Bank and Firm Characteristics

Linear Bank Interaction	$\Delta KR_{i,t}$	$1/(1+L_{i,t})$	$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	$\Delta KR_{i,t} \times Variable$	$\Delta KR_{i,t} \times 1/(1+L_{i,t}) \times Variable$
(1) Core Funding Ratio	0.0159	0.402***	-0.0744	-0.0000345	0.0000433
(2) Liquidity Ratio	0.0263**	0.494***	-0.140***	-0.00817	0.0417*
(3) Leverage	0.0113	0.510***	-0.04	0.000151	-0.00225
(4) Capital Buffer	0.0253***	0.474***	-0.132***	0.00277**	.01417**
(5) Trading/BankingBook	0.00232	0.0485	0.0565	0.0126	-0.139
Non-Linear (quartile dummy) Bank Interaction	$\Delta KR_{i,t}$	$1/(1+L_{i,t})$	$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	$\partial\Delta\ln(TA)/\partial KR$ For High Value	$\partial\Delta\ln(TA)/\partial KR$ For Low Value
(6) Core Funding Ratio	0.0108*	0.447***	-0.0459	-.064***	-.25
(7) Liquidity Ratio	0.0201***	0.470***	-0.0731**	-.033	-.34
(8) Leverage	0.0107**	0.463***	-0.0549**	-.104***	-.53*
(9) Capital Buffer	0.00955**	0.466***	-0.0536**	-.046	-.19***
(10)Trading/BankingBook	0.00539	0.513***	-0.0339	-.32***	-.026
Non-Linear (quartile dummy) Firm Interaction	$\Delta KR_{i,t}$	$1/(1+L_{i,t})$	$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	$\partial\Delta\ln(TA)/\partial KR$ For High Value	$\partial\Delta\ln(TA)/\partial KR$ For Low Value
(13) Age	0.013***	0.469***	-0.07***	-0.03	-0.05
(14) Credit Risk	0.014***	0.461***	-0.071***	-0.063**	-0.045*
(15) Leverage	0.017***	0.474***	-0.098***	-0.05	-0.056*
Estimate Model by Sector					
(16) CRE	0.0204**	0.575***	-0.116***		
(17) Wholesale	0.00309	0.343***	-0.0163		
(18) Manufacturing	0.000795	0.263***	-0.0314		
(19) Retail	0.019*	0.434***	-0.069		
(20) Other	0.0152**	0.427***	-0.0571*		

Table 6: Monetary Policy (MP Measure -1)

			$1/(1+L_{i,t})$	$MP_t \times 1/(1+L_{i,t})$
Baseline regression				
(1) With sector*area*year effects			0.467***	-0.062***
(2) With bank year effects			0.478***	-0.039****
Split Sample by Bank size				
(3) Big Banks – Sector*area*year effects			0.447***	-0.0378**
(4) Small Banks – Sector*area*year effects			0.534***	-0.146***
(5) Big Banks – Bank*year effects			0.453***	-0.0204
(6) Small Banks – Bank*year effects			0.563***	-0.103***
Non-Linear Firm Interaction	$1/(1+L_{i,t})$	$\Delta MP_t \times 1/(1+L_{i,t})$	$\partial\Delta\ln(TA)/\partial MP$ For High Value	$\partial\Delta\ln(TA)/\partial MP$ For Low Value
(7) Credit Risk – sec*area*year	0.425***	0.00573	-0.159***	-0.0444**
(8) Credit Risk – Bank*year	0.438***	-0.0490***	-0.0833***	-0.0329*
Split Sample by Sector			$1/(1+L_{i,t})$	$MP_t \times 1/(1+L_{i,t})$
(9) Commercial Real Estate			0.588***	-0.116***
(10) Wholesale			0.364***	-0.0473*
(11) Manufacturing			0.287***	-0.0619*
(12) Retail			0.437***	-0.0322
(13) Other			0.439***	-0.0663**

Table 7 – The Interaction of Capital Requirements with Monetary Policy

	(1)	(2)	(3)	(4)
$\Delta KR_{i,t}$	0.0112**	0.00800**	-0.0241**	0.00908
	(0.00438)	(0.00363)	(0.00993)	(0.0044
$1/(1+L_{i,t})$	0.466***	0.473***	0.476***	0.469***
	(0.0115)	(0.00972)	(0.00969)	(0.0115
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	-0.0608***	-0.0405**	-0.0394**	-.051**
	(0.0198)	(0.0171)	(0.0173)	(0.0205
$MPshock_t \times 1/(1+L_{i,t})$	-0.0689***	-0.0593***	-0.0444***	-.067***
	(0.0176)	(0.0141)	(0.0145)	(0.0175
$\Delta KR_{i,t} \times MPshock_t$		0.0562***	0.110***	0.0422*
		(0.0157)	(0.0419)	(0.0196
$\Delta KR_{i,t} \times MPshock_t \times 1/(1+L_{i,t})$		-0.153**	-0.0688	-0.153*
		(0.0686)	(0.0691)	(0.0822
Lagged Firm Controls	X	X	X	X
Year Effects		X		
Bank Year Effects			X	
SIC4dig×Postcode ×Year Effects	X			X
Observations	870,168	871,131	871,131	871,131
N of firms	196,980	196,980	196,980	196,980
R-Squared	0.445	0.334	0.334	0.334

This table presents the results for the interaction with monetary policy. The dependent variable is the log difference of total assets by firm i between time t and t-1. All specifications include firm fixed-effects and the SIC4dig*postcode- area*year fixed-effects. All specifications include the following lagged firm variable and are fully saturated, but the some double interactions coefficients are not shown. $MPshock_t$ is a monetary policy shock constructed from a Taylor rule fitted on UK data (see Appendix B for details). Given that $MPshock_t$ is an aggregate time shocks, they are absorbed by the time fixed-effects. Firm-clustered standard errors are reported in parenthesis.

Table 8 – The Interaction with Monetary Policy – Large and Small Banks

	Sector Area Time Effects			Bank Year Effects		
	All	Small Banks	Big Banks	All	Small Banks	Big Banks
$\Delta KR_{i,t}$	0.00819*	-0.0162	0.00979**	-.0268**	-0.0756**	-0.0234*
	(0.00446)	(0.0197)	(0.00472)	(0.0115)	(0.0315)	(0.0125)
$1/(1+L_{i,t})$	0.474***	0.561***	0.450***	0.480***	0.587***	0.452***
	(0.0108)	(0.0253)	(0.0124)	(0.0105)	(0.0230)	(0.0120)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	-0.0475**	0.0552	-.0607***	-.0447**	0.0850	-.0569***
	(0.0207)	(0.0782)	(0.0220)	(0.0202)	(0.0729)	(0.0211)
$\Delta KR_{i,t} \times TIGHT_t$	0.00581	0.0527**	-0.0149	0.0285	0.0978**	0.0181
	(0.00883)	(0.0237)	(0.0116)	(0.0226)	(0.0419)	(0.0318)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	-0.0171	-0.221**	0.0925*	0.00289	-0.204**	0.0925*
$\times TIGHT_t$	(0.0386)	(0.0953)	(0.0497)	(0.0374)	(0.0878)	(0.0478)
Partial effects for new borrowers (length=0)						
∂TA/∂DKR	-0.04**	0.03	-0.05***	-0.07***	0.009	-0.08***
∂TA/∂DKR$\|TIGHT_t = 1$	-0.05**	-0.129***	0.026	-0.04	-0.097**	0.03
Lagged Firm Controls	X	X	X	X	X	X
Bank Year Effects				X	X	X
SIC4dig×Postcode×Year Effects	X	X	X			
Observations	870,168	196,981	673,187	871,131	197,887	673,244
R-squared	0.363	0.444	0.363	0.334	0.376	0.329

This table presents the results for the interaction with monetary policy between large and small banks. The dependent variable is the log difference of total assets by firm i between time t and t-1. All specifications include firm fixed-effects and the SIC4dig*postcodearea*year or bank-year fixed-effects All specifications include the following lagged firm variables, not shown: $CredScore_{i,t-1}$, $Currliab/TA_{i,t-1}$ and $young, old$. All specifications are fully saturated, but the some double and triple interactions coefficients are not shown. $MPshock_t$ is a monetary policy shock constructed from a Taylor rule fitted on UK data (see Appendix C for details). $TIGHT_t$ is a dummy variable that takes value one if the monetary policy surprise is positive and zero otherwise. Given that $MPshock_t$,, $TIGHT_t$ are aggregate time shocks, they are absorbed by the time fixed-effects, so their coefficients are not shown in the regression. Firm-clustered standard errors are reported in parenthesis.

Table 9 – Impact of Capital Requirements by Sectoral Bank Dependence

	(1)	(2)
$\Delta KR_{i,t}$	0.03***	0.015***
	(0.008)	(0.004)
$1/(1+L_{i,t})$	0.561***	0.460***
	(0.019)	(0.012)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	-0.134***	-0.079***
	(0.0360)	(0.021)
$BLnonreg/BLreg$	0.017***	
	(0.006)	
$\Delta KR_{i,t} \times BLnonreg/BLreg$	-.00053***	
	(0.001)	
$1/(1+L_{i,t}) \times BLnonreg/BLreg$	-.003***	
	(0.0003)	
$\Delta KR_{i,t} \times 1/(1+L_{i,t}) \times BLnonreg/BLreg$	0.002**	
	(0.0008)	
Nonbank/BLreg		0.005*
		(0.003)
$\Delta KR_{i,t} \times Nonbank/BLreg$		-.000550
		(0.003)
$1/(1+L_{i,t}) \times Nonbank/BLreg$		-.0001**
		(.00001)
$\Delta KR_{i,t} \times 1/(1+L_{i,t}) \times Nonbank/BLreg$		0.0002
		(0.001)
∂TA/∂DKR	-0.1039***	-0.0639***
∂TA/∂DKR for a one std.dev.increase in (BLnonreg) or (Nonbank)	-0.0721***	-0.0491***
Firm Fixed Effects	X	X
SIC4dig×Postcode ×Year Effects	X	X
Observations	860,355	860,355
N of firms	193,900	193,900
R squared	0.443	0.443

The dependent variable is the log difference of total assets by firm *i* between time *t* and *t-1.* All specifications include firm fixed-effects and the SIC4dig*postcode-area*year and lagged firm controls. $BLnonreg/BLreg$ is the ratio between the lending by branches of foreign banks (not FSA regulated) and that by UK resident banks (FSA regulated) at the sector level. $Nonbank/BLreg$ is the ratio between capital market funding (equity+bonds outstanding) over the lending by UK resident banks. Firm-clustered standard errors are reported in parenthesis.

Table 10 – The Impact of Multiple Banks on Capital Requirement and Monetary Policy Transmission

	MP-1	MP-2	MP-3
	(1)	(2)	(3)
$\Delta KR_{i,t}$	0.0126***	0.0126***	0.0136***
	(0.00465)	(0.00465)	(0.00464)
$1/(1+L_{i,t})$	0.436***	0.434***	0.445***
	(0.0122)	(0.0120)	(0.0124)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	-0.0611***	-0.0609***	-0.0655***
	(0.0215)	(0.0215)	(0.0214)
$MPshock_t \times 1/(1+L_{i,t})$	-0.0457**	-0.0313**	-0.0843***
	(0.0180)	(0.0122)	(0.0155)
$\Delta KR_{i,t} \times bank2dummy$	-0.0163	-0.0162	-0.0150
	(0.0129)	(0.0129)	(0.0129)
$\Delta KR_{i,t} \times 1/(1+L_{i,t})$	0.0400	0.0398	0.0300
$\times\ bank2dummy$	(0.0582)	(0.0582)	(0.0582)
$MPshock_t \times 1/(1+L_{i,t})$	-0.0284	-0.0200	-0.0345*
$\times\ bank2dummy$	(0.0224)	(0.0152)	(0.0193)
Partial effects for new borrowers (length=0)			
$\partial\Delta \ln(TA)/\partial KR$ for 2 Relationship Banks	-.024	-.024	-.035
$\partial\Delta \ln(TA)/\partial MP$ for 2 Relationship Banks	-.075***	-.051***	-.12***
Firm Fixed Effects	X	X	X
SIC4dig×Postcode×Year	X	X	X
Lagged Firm Controls	X	X	X
Observations	849,228	849,228	849,228
N of firms with two banks	26,952	26,952	26,952
R squared	0.448	0.448	0.448

This table presents the results for firms with multiple (two) banks relationship on the effects of capital requirements and monetary policy. The dependent variable is the log difference of total assets by firm *i* between time *t* and *t-1*. All specifications include firm fixed-effects and the SIC4dig*postcode-area*year fixed-effects. $bank2dummy$ is a dummy that takes value one if the firm has two banks and interacts with the change in capital requirement for that bank. Firm controls are: $CredScore_{i,t}$, $Currliab/TA_{i,t}$ and $young, old$.

FOR ONLINE PUBLICATION

Appendix A – Exogeneity of $\Delta KR_{j,t}$

An important assumption within our regression framework is the exogeneity of changes in the capital requirement with respect to bank balance sheet variables. Our argument that this condition is satisfied relies on anecdotal evidence from speeches of senior policy makers and FSA reports during the time that regulatory changes took place. In this section we explore this assertion formally.

Specifically, we test if bank balance sheet variables that supervisors had access to at the time of the regulatory decision can statistically predict the regulatory change. If this is the case and the predictors can explain a high fraction of the variation in capital requirements, then our initial assertion would have been invalid. If all relevant balance sheet variables have been included in the predicting model, then the residual will reflect capital requirement changes that reflect non-balance sheet risk. We can therefore use the residual to verify if the results change when we use these "non-balance sheet based" capital requirement changes in our model.

We have collected 23 such variables (Table 1A). The first 12 variables are taken from the regulatory returns form, the BSD3 form. This is the form that records capital requirements. Of course, supervisors could have also relied on additional balance sheet information that was not recorded on the BSD3 form. We therefore also use additional balance sheet information, such as the change in different sectors, scaled by lagged total assets, and the change in the liquid asset and core funding ratio. We then explore if changes in capital requirements can be predicted by any of these variables with the following regression framework:

$$\Delta KR_i = \beta \Delta X_i + \varepsilon_i$$

Where ΔKR_i is the non-zero change in capital requirement for bank i and ΔX_i is the matrix of the changes in the exogenous variables that helps to predict this particular instance of ΔKR_i.

We use this regression framework in three different ways to isolate the predictors of changes in capital requirements. First we regress each individual predictor against the change in the capital requirement with a single regression. Then we run a multi-variate regression, including all of the predictors together. However, we have little information on whether supervisors looked at these indicators together or individually to form their judgement about a capital requirement change. Given 23 variables, there are over 8 million linear regression models that could be explored for this purpose. We therefore follow the Bayesian Modelling approach proposed in the economic growth literature (Doppelhofer, Miller and Sala-i-Martin (2004)) to explore all of these possible model combinations. Due to the inherent model uncertainty, we only use predictors which are found to be statistically significant in all three approaches.

Table 1A presents the results from this exercise. This suggests that the change in total loans scaled by total assets in the previous period, change in total interest rate risk and total profits&losses scaled by risk-weighted assets in the previous period are the most important predictors of capital requirement changes. We select these variables and run a regression in Table 2A. According to the R^2 in column (1) they can only explain 30% of the variation in capital requirements The residual from the regression in column (1) will yield our first measure ΔKR_Exog1 . In the regression in column (2), we also add another important control variable: the change in the capital buffer. We abstained from including this variable in the original variable selection framework since, given a constant capital to risk-weighted asset ratio, the change in the capital buffer will be correlated with the change in the capital requirement almost by construction. But adding the change in the capital buffer increases the R^2 to 36%. The residual from this regression will yield ΔKR_Exog2

Charts 1A and 2A show these residuals plotted against actual capital requirement changes. Consistent with the regression results, this suggests that the majority of capital requirement changes were due to non-balance sheet risk. It is therefore not surprising that the results ΔKR_Exog1 and ΔKR_Exog2 are very similar to those obtained with the baseline specification.

Table 1A: Models for selecting DBBKR predictors

Variable	Single Regression		Multiple		BMA		
DKR	Coeffcient	T-	Coeffcient	T-	Coeffcient	T-	PIP
Δ Government	-0.180	-.68	-0.055	-.55	-0.010	-.24	0.09
Δ MBS Investment	-0.105	-.22	0.188	0.4	0.001	0.01	0.04
Δ Writeoffs	0.543	2.51	0.093	0.44	0.014	0.19	0.07
Δ Provisions	0.939	3.58	0.208	0.66	0.093	0.37	0.16
Δ Profits & Losses on	-0.987	-.75	1.722	1.21	0.016	0.05	0.05
Δ Profits & Losses on	-1.083	-.01	0.875	0.78	0.067	0.19	0.07
Δ Total Profits & Losses	-0.456	-.04	-0.316	-2.3	-0.347	-.23	0.9
Δ Counterparty Risk	-1.944	-.14	-3.389	-.95	-0.811	-.52	0.27
Δ Total FX Risk	24.170	2.91	14.658	1.45	0.804	0.21	0.08
Δ Total Interest Rate	2.080	1.81	3.251	2.47	3.646	2.76	0.95
Δ Total Equity Risk	-2.254	-0.36	-14.920	-1.93	-2.759	-0.48	0.24
Δ Total Commodity	19.97	1.09	-8.400	-0.46	0.006	0	0.04
Δ Banking Book	-0.000125	-0.14	0.000	0.2	0.000	-0.11	0.05
Δ Financial Lending	-0.276	-2.23	-0.002	-0.02	-0.007	-0.17	0.06
Δ PNFC Lending	-0.119	-1.13	0.052	0.31	0.003	0.1	0.06

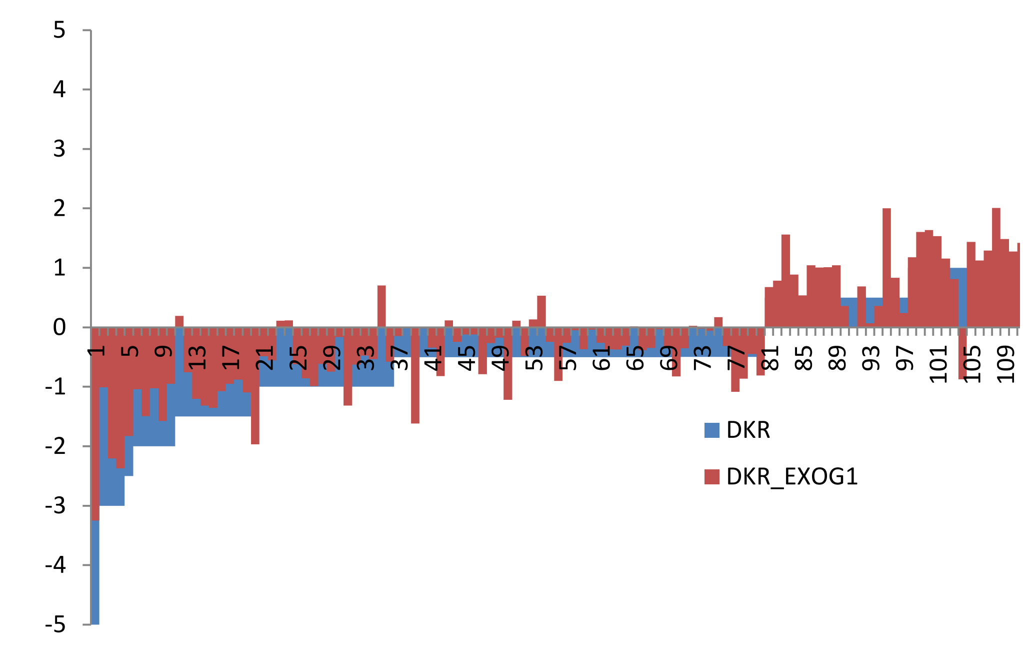
Δ Household Lending	-0.228	-1.77	-0.091	-0.73	-0.010	-0.21	0.08
Δ Total Lending	-0.031	-4.06	-0.043	-4.01	-0.039	-4.5	1
Δ Wholesale/Retail	-0.564	-0.92	-0.689	-1.11	-0.025	-0.14	0.06
Δ Construction Lending	1.378	1.19	2.987	2.49	0.975	0.74	0.42
Δ Manufacturing	-0.131	-0.32	0.084	0.19	0.012	0.12	0.05
Δ Commercial Real	-0.315	-1.38	-0.143	-0.53	-0.002	-0.05	0.05
Δ Liquid Assets	0.0199	1.02	0.021	1.05	0.001	0.2	0.07
Δ Corefunding	-0.0482	-1.36	-0.011	-0.32	0.000	-0.05	0.04

Table 2A: Regressions to Remove Balance sheet risk DKR Changes

	(1)	(2)
Δ Total Profits & Losses	-0.397***	-0.292***
	(0.103)	(0.102)
Δ Total Interest Rate Risk	3.875***	2.921***
	(1.051)	(1.034)
Δ Total Lending	-0.0373***	-0.0331***
	(0.00737)	(0.00711)
Δ Capital Buffer		-0.158***
		(0.0431)
Observations	125	125
R squared	0.293	0.364

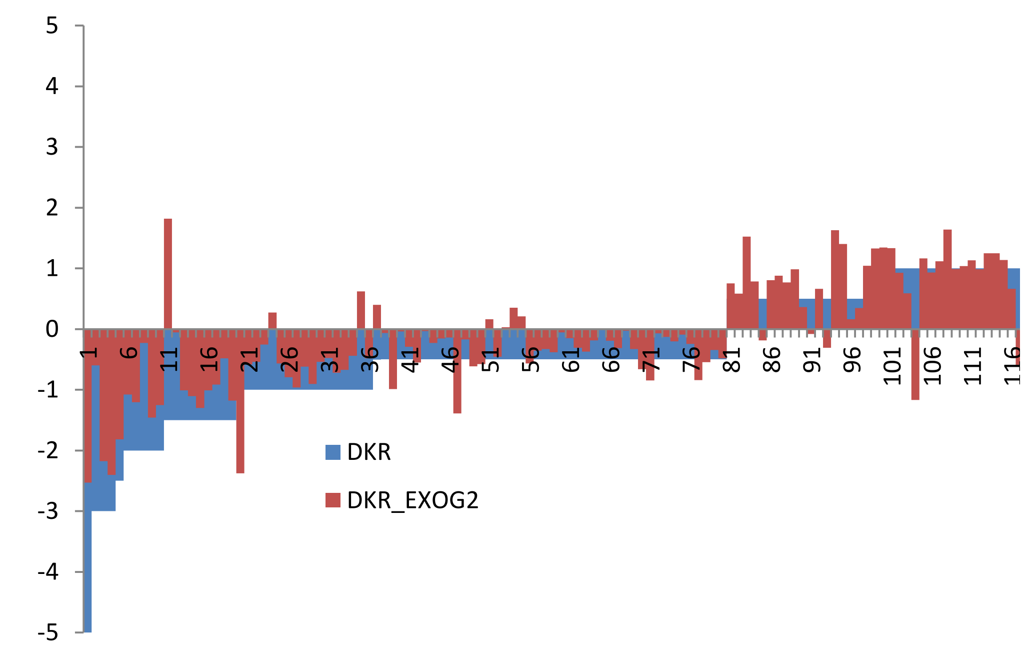
This table presents the results for predicting 125 changes in capital requirements with risk and lending variables. Specification (1) is implied by the model selection procedure in table 1A. We refer to the residuals from this specification as *DKR_exog1*. The change in the capital buffer can also explain a significant variation of the R2 (7%), but this could because the variables might be correlated by construction. As a result we include this variable in column 2 separately and refer to the residual from column (4) as DKR_exog2 for the rest of this paper.

CHART 1A: DKR vs DKR_Exog1



Source: Authors Calculation.

CHART 2A: DKR vs DKR_Exog2



Source: Authors Calculation.

Details on Bayesian Model Averaging

In this section we provide more detail on our implementation of Bayesian Model Averaging. We have up to 23 (k) possible predictors of the change in capital requirements, but only some of these predictors seem to matter the most for regulatory decision. The economic growth literature has proposed Bayesian Model Averaging to objectively determine which variable has the highest explanatory power. We follow this approach here to select the best predictors of changes in capital requirements based on their posterior inclusion probabilities.

The idea underlying Bayesian Model Averaging is to consider the results for all the models which include all possible combinations of the regressors and average them. In our case there are 2^k or up to 8,388,608 models. The weights in the averaging are given by the posterior model probabilities $p(M|y)$ where M is the model and y is the data. In order to compute the posterior model probabilities by means of Bayes rule, two elements are required. First, we need the posterior distribution of the parameters in each model M, which is used to derive the marginal likelihood $p(y|M)$. Second, we need to specify the prior distribution of the models $p(M)$. With marginal likelihood and model prior distributions at hand, the model posterior probabilities can be derived as

$$p(M|y) \propto p(y|M)p(M)(9)$$

As to the setup of the priors, we follow Fernandez, Ley and Steel (2001). In particular, for each model, we compute the posterior probability distribution of the parameters by assuming an uninformative prior on the variance of the residuals and on the intercept. For the remaining regression coefficients we use the g-prior of Zellner (1986), setting $g = \frac{1}{\max(N,k^2)}$ .We set a uniform prior for the distribution of the models. We evaluate each one of them to obtain the exact likelihood, without having to rely on MCMC methods for approximation. High posterior inclusion probabilities indicate that, irrespective of which other explanatory variables are included, the regressor has a strong explanatory power.

APPENDIX B - MONETARY POLICY MEASURE

In this appendix we describe our proposed measure of monetary policy surprises. Ideally, we would use an established measure of monetary policy shocks for the UK, similar to the measure proposed by Romer and Romer (2004) for the US.[9]

[9] Obtaining an equivalent measure for the UK is not straightforward, given the presence of seven different monetary policy regimes between 1972 to 1997 (Nelson (2001)). Cloyne and Huertgen (2014)

After 1997, the Bank of England gained operational independence to choose policy to implement the inflation target set by the government. During the time period of relevance here, 1998-2007, the Bank of England used the "*Bank Rate*", the overnight rate on sterling denominated central bank reserve assets, as it main policy instrument. The Monetary Policy Committee's main objective was to keep inflation on at target at the 2-year horizon, subject to minimising volatility in output. The Taylor rule we estimate is the following

$$i_t = \rho + \varphi_\pi \pi_t^{BOE\_f} + \varphi_y y_t^{BOE\_f} + \varepsilon_t$$

where $\pi_t^{BOE\_f}$ and $y_t^{BOE\_f}$ are the Bank of England's inflation and GDP forecasts, respectively. We would like a measure of monetary policy surprises, since economic agents may have already reacted in anticipation of the announcement. Therefore, we need to measure agents' expectation of $\pi_t^{BOE\_f}$ and $y_t^{BOE\_f}$. While measuring expectations is not easy, the Bank of England surveys professional forecasters, the week before the Bank's official forecast is announced. We use the mean of these professional forecasters forecast as our measure of agents' expectation of the MPC's forecast. Subtracting this actual announced forecast from this expectation yields inflation and real GDP growth forecast surprises. *i.e.* $\pi_t^{SUR\_f} = \pi_t^{BOE\_f} - E_{t-1}\pi_t^{BOE\_f}$ and $y_t^{SUR\_f} = y_t^{BOE\_f} - E_{t-1}y_t^{BOE\_f}$. We then construct the interest rate surprise measure, $i_t^{SUR\_f}$, based on the following equation:

$$i_t^{SUR\_f} = \varphi_{i_{t-1}} i_{t-1}^{SUR\_f} + (1 - \varphi_{i_{t-1}})(\varphi_\pi \pi_t^{SUR_f} + \varphi_y y_t^{SUR_f})$$

For our first measure of the interest rate surprise, we set $\varphi_{i_{t-1}}$ to zero and φ_π to 1.5 and φ_y to 1. Figure 1C shows our measure together with the "Bank Rate". This suggests that the two series co-move especially during tightening and loosening cycles, when surprises are likely to be larger, with an overall correlation coefficient of .53.

To ensure that our results are robust to different Taylor rule coefficients we also constructed this monetary policy series with alternative Taylor rule coefficients, all of which are shown in table 1C. The resulting time series, along with the change in the "Bank Rate", are shown in Figure 8. The resulting five different measures of monetary policy are all displayed in Figure 8. They are all clearly highly correlated with the proposed baseline measure. Only the 'alternative Taylor rule 3' and 'alternative Taylor rule 4' (with a smoothing coefficient on the interest rate) are markedly different from each other.

construct such a Romer and Romer (2004) measure, but at the time of writing this series was not yet ready to be shared publicly.

While no monetary policy measure is likely to be perfect, given the properties of our measure and the co-movement with bank rate during tightening and loosening cycles, we believe that our measure does indeed reflect monetary policy surprises and it hence suitable for our purposes.

Figure 1B: UK Bank rate and Interest rate surprise

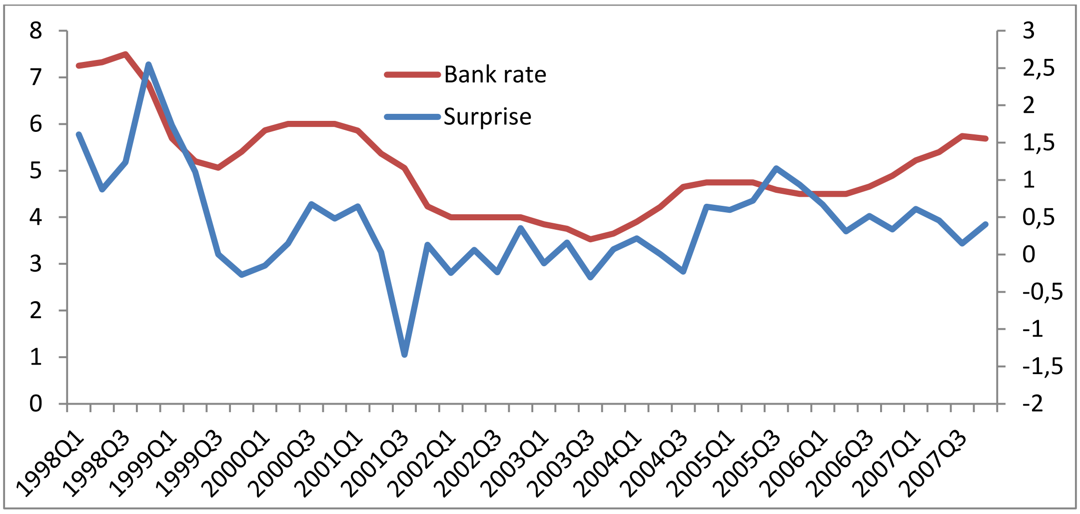
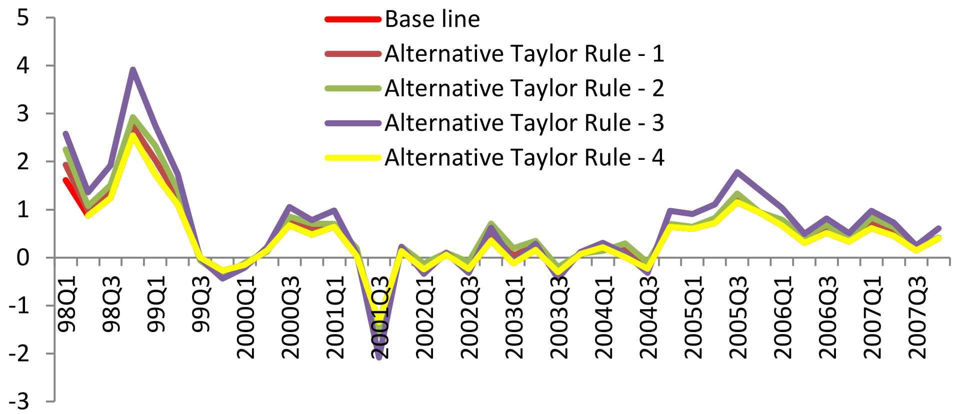


Figure 2B: Monetary Policy (Taylor Rule) and Alternatives



<u>Note</u>: This figure plots the estimated Taylor rule for the UK economy: a linear combination of the surprises to CPI inflation and GDP forecast using the estimated Taylor coefficients of 1.5 and 1 for the baseline. Alternative Taylor rules with different coefficients are specified in Table 1B

Table 1B

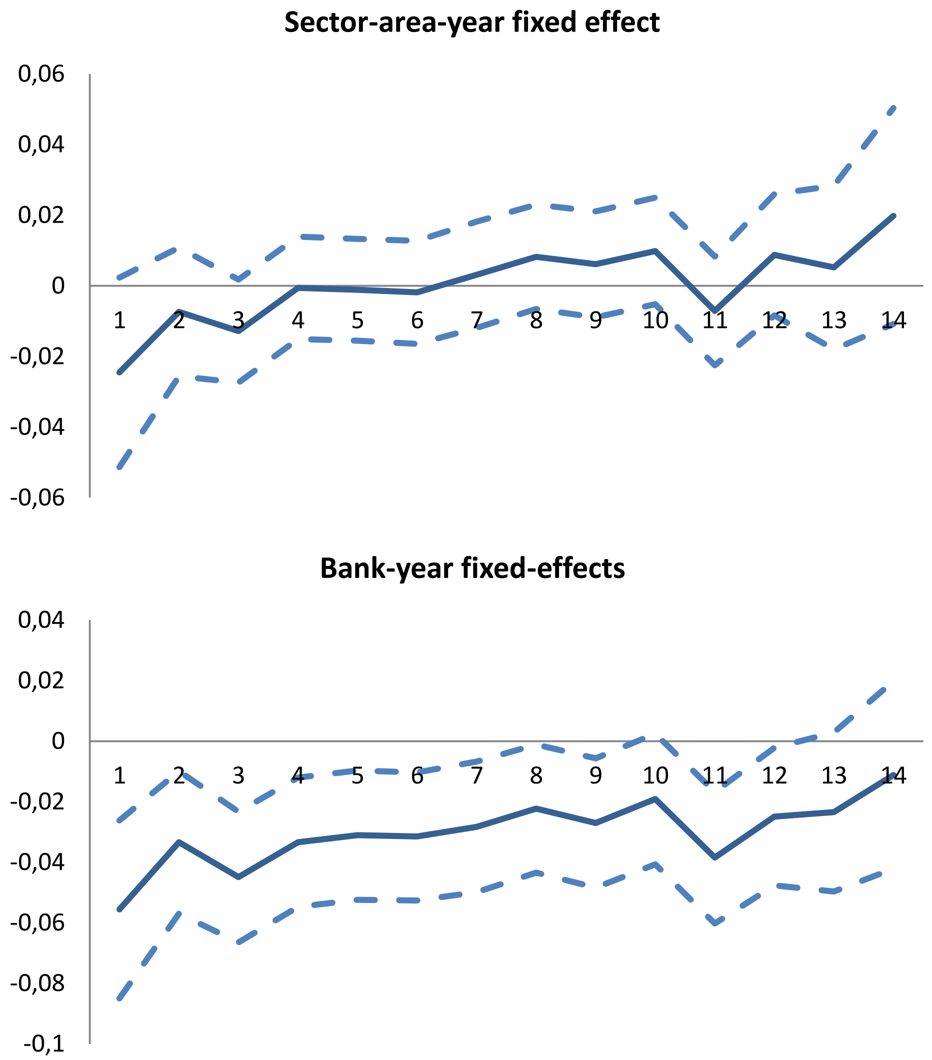
Taylor Rule Coefficients	Base -line	Alternative Rule 1	Alternative Rule 2	Alternative Rule 3	Alternative Rule 4
φ_{π}	1.5	2	2.5	2.5	1.5
φ_{y}	1	1	1	2	1
$\varphi_{i_{t-1}}$	-	-	-	-	0.5

Table 2B

	Bankrate	Bankrate	Bankrate
CPI Inflation	-0.127		
	(0.338)		
Real GDP Growth	-0.233		
	(0.463)		
Annual CPI Inflation		-0.172	
		(0.257)	
Annual Real GDP Growth		-0.131	
		(0.160)	
2-Year Inflation Forecast			1.447***
			(0.459)
2-Year Real GDP Growth Forecast			0.987**
			(0.427)
Constant	5.277***	5.527***	-0.955
	(0.419)	(0.714)	(1.715)
Observations	40	37	40
R-squared	0.009	0.025	0.258

Appendix C

Figure 1C: Non-parametric regression



Note: This figure plots the coefficients from a non-parametric regression of a change in capital requirement interacted with 15 dummies, one for each year of length, on firms' growth rate of assets. The upper panel contains 4digitsect*area*year fixed effect, while the lower panel includes also bank*year effects. The dashed lines show the 95% confidence interval around the point estimate.