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ABSTRACT

The regulation of bank capital as a means of smoothing the credit cycle is a central element of forthcoming macro-prudential regimes internationally. For such regulation to be effective in controlling the aggregate supply of credit it must be the case that: (i) changes in capital requirements affect loan supply by regulated banks, and (ii) unregulated substitute sources of credit are unable to offset changes in credit supply by affected banks. This paper examines micro evidence—lacking to date—on both questions, using a unique dataset. In the UK, regulators have imposed time-varying, bank-specific minimum capital requirements since Basel I. It is found that regulated banks (UK-owned banks and resident foreign subsidiaries) reduce lending in response to tighter capital requirements. But unregulated banks (resident foreign branches) increase lending in response to tighter capital requirements on a relevant reference group of regulated banks. This "leakage" is substantial, amounting to about one-third of the initial impulse from the regulatory change.

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1 Introduction

Capital requirements have been a central tool of the prudential regulation of banks in most countries for the past three decades. Recently, under Basel III, regulators have agreed to vary minimum capital requirements somewhat over time, as part of the cyclical mandate of macro-prudential policies.[1] During boom times, capital requirements would increase, and during recessions they would decline. That variation is intended to achieve three macro-prudential goals: (1) cooling off credit-fed booms with higher capital requirements, (2) mitigating credit crunches during recessions with commensurate reductions in capital requirements, and (3) boosting capital and provisioning requirements during booms to provide an additional cushion to absorb losses during downturns.[2]

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

Before undertaking our empirical analysis in Sections 2 through 4, we begin by reviewing the theoretical foundations of macro-prudential capital regulation and the empirical literature relating to those foundations. Three necessary conditions must hold true if the time-varying, macro-prudential capital requirements envisioned under

[1] In addition to cyclical variation of capital ratios, macro-prudential policy could entail other cyclical variation in policy instruments (e.g., liquidity and provisioning requirements) as well as "structural" interventions to promote financial stability. For more details, see Tucker (2009, 2011), Galati and Moessner (2011), Bank of England (2009), and Aikman, Haldane and Nelson (2010).

[2] As regulations have evolved over time, the complexity of capital regulation has also increased. Under the Basel I system, capital requirements consisted of three ingredients: definitions of capital that distinguished between tier 1 and tier 2 capital, a formula for measuring risk-weighted assets, and setting constant minimum ratios of 8% for the total risk-based capital (defined as the sum of tier 1 and tier 2 capital, divided by risk-weighted assets), and 4% for the tier 1 risk-based capital. Under Basel II, the calculation of risk-weighted assets was modified to permit, under some circumstances, the use of internal models and rating agency opinions. Under Basel III, the Basel I minimum ratio is being raised, with a greater focus on the common equity component of capital, and the so-called "counter-cyclical capital buffer" implies that minimum risk-based capital ratios will now vary over the economic cycle.

Basel III are to be effective in controlling system-wide credit growth: (1) equity (the key variable of interest in bank capital regulation) must be a relatively costly source of bank finance, (2) minimum capital requirement ratios must have binding effects on banks' choice of capital ratios, and (3) when macro-prudential regulation diminishes (increases) the supply of credit by banks subject to macro-prudential policy, other sources of credit must not fully offset such changes through increases (decreases) in the credit supplied by other sources.

Necessary Condition 1: Equity Must Be a Relatively Costly Source of Finance

The supply of loans from regulated banks will not respond to changes in capital requirements unless bank capital is a relatively costly means of financing bank activities. If bank leverage were irrelevant to the cost of bank finance – as implied by the Miller-Modigliani Theorem – then changes in minimum capital requirements would not be useful in reducing credit growth during booms or in mitigating credit crunches; banks would costlessly adjust their capital ratios without any effect on their lending activities.

Theoretical models that incorporate the tax benefits of debt finance and asymmetric information about banks' conditions and prospects imply that, in general, raising funds from external equity finance is more costly for banks than from debt finance, which implies that a rise in capital requirements will raise the cost of bank finance, and thus lower the supply of lending.[3] The favourable tax treatment of debt results from the deductibility of interest payments, but not dividend payments.

With respect to the asymmetric information costs of equity, Myers and Majluf (1984) show that the adverse-selection costs of raising external equity (which take the form of under-pricing of the equity offerings of unobservably healthy banks in their

[3] There is also a theoretical literature in banking that discusses how agency problems arising from greater capital or capital requirements can give rise to social costs in addition to credit contraction – for example, changes in managerial effort or risk preferences. We do not describe this literature, since it is not directly related to the amount of lending, which is our focus. For a review of that literature, see VanHoose (2008) and Kashyap, Rajan and Stein (2008). Admati et al. (2011) express scepticism about the magnitude of equity capital costs for banks.

model) apply more to junior securities (like equity) than to relatively senior debt instruments.[4]

Equity may also be relatively costly as a source of finance because of ex post verification costs, another form of asymmetric information. For example, Diamond (1984) and Gale and Hellwig (1985) show that banks that offer debt contracts can economize on those costs.[5]

The negative signalling effects of equity offerings modelled by Myers and Majluf (1984) will be mitigated if equity offerings respond to an observable regulatory change, and so, the raising of equity capital to respond to observable changes in macro-prudential regulation will have a lower cost than the raising of equity in response to unobservable changes in requirements or other unobservable motivations for raising new equity. That does not imply, however, that the imposition of observably higher regulatory capital requirements would eliminate the negative signalling effects of choosing to issue equity to meet higher regulatory requirements.

In equilibrium, bank heterogeneity would also result in differences among banks in the extent to which they would choose to raise equity as opposed to shrinking their risk-weighted assets in response to higher capital requirements. Banks in relatively good condition would eschew equity offerings more, ceteris paribus, to avoid long-term dilution of incumbent stockholders. For these reasons, higher equity capital requirements do not eliminate the information costs, and attendant adverse selection risks, that make equity offerings relatively costly.[6]

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[4] The Myers and Majluf (1984) model envisions adverse-selection costs as entirely reflected in the pricing of an equity offering, since in their model, there is no technology available to firms to invest in overcoming problems of asymmetric information. More realistically, part of the cost of asymmetric information takes the form of paying high underwriting costs to investment bankers who market equity offerings. Firms pay those costs to mitigate the more severe adverse pricing effects on equity offerings that otherwise would result from asymmetric information (Calomiris and Tsoutsoura 2011).

[5] Additionally, Calomiris and Kahn (1991) show that agency problems associated with asymmetric information about portfolio realizations will tend to encourage demandable debt contracting rather than long-term debt issuances (in their model, equity is supplied entirely by insiders). In that model, requiring bankers to raise the ratio of equity to risky assets would result in less lending by banks (since outside equity finance is prohibitively expensive. That model is extended by Diamond and Rajan (2000, 2001).

[6] Additionally, even if all banks went to the equity market at the same time to raise equity, banks would differ according to their investment banking choices; banks whose managers knew that they were in better condition would have an incentive to expend more on underwriting to ensure that investors receive more information about their superior condition. Those expenditures contribute to the costs of equity capital requirements, and would also have signalling effects on the pricing of both high-underwriting cost and low-underwriting cost banks.

There is a substantial empirical literature in support of the general proposition that equity capital is relatively costly to raise, and that the financing costs of debt sources of funding increase in the extent to which the debt claim is more equity-like – that is, costs are lowest for deposits, higher for contractual debt and preferred stock (which are de jure junior to deposits in many countries and also de facto junior because of their longer maturity), higher still for mezzanine instruments (e.g., debt that is convertible into equity), and highest for equity.[7] Equity prices tend to decline in reaction to an announcement of an equity offering, especially when issuers are informationally opaque, and that announcement effect is lower for convertible debt, and zero for straight debt (James 1987, James and Wier 1990). Underwriting costs for equity are also much higher than for debt (Calomiris 2002). Ediz et al (1998) and Francis and Osborne (2009) also find that, consistent with Myers and Majluf (1984), UK banks behave as if tier 2 capital is less costly to raise than equity, and that banks that have relatively low costs of raising equity raise equity capital more (as opposed to contracting risky assets) in response to increases in capital requirements.

Because the high cost of equity capital is a necessary condition for credit supply to respond to either a loss of equity capital or an increase in capital requirements, evidence that contractions of credit result from these phenomena is powerful evidence that equity finance is costly. The literature on bank "capital crunches" documents that shocks to bank equity capital have large contractionary effects on the supply of lending (Bernanke 1983, Bernanke and Lown 1991, Kashyap and Stein 1995, 2000, Houston, James, and Marcus 1997, Peek and Rosengren 1997, 2000, Campello 2002, Calomiris and Mason 2003, Calomiris and Wilson 2004, Cetorelli and Goldberg 2009).

Many studies also suggest that increases in regulatory capital requirements can precipitate contractions in the supply of credit (see VanHoose 2008 for a review). Some of these existing studies analyze banks' lending behaviour around the time of regulatory regime changes (Chiuri et al. 2002), and thus do not isolate the effects of bank minimum capital requirement changes, per se. Others analyze cross-sectional

[7] The view that junior instruments are more costly sources of finance also explains the common regulatory reluctance to impose large increases on banks' minimum capital ratios. The initial Basel minimum capital requirements were set at ratios that were quite close to those prevailing at the time. Indeed, the distinctions between tier 1 and tier 2 capital, and the 4% and 8% minimum risk-based capital ratios, were devised in 1988 to allow banks that were subject to the Basel guidelines to comply with the new guidelines without raising significant new capital, and despite significant differences in the capital structures of banks across countries.

differences in lending by banks that differ according to their regulatory circumstances, including whether they are the subject of a regulatory action, or whether they have relatively small buffers of capital relative to the minimum requirement (e.g., Peek and Rosengren 1995a, 1995b, Gambacorta and Mistrulli 2004). Experiencing a regulatory action is a special event, however, and one that is highly endogenous to a variety of circumstances that may affect bank lending. Similarly, the relative sizes of banks' capital buffers do not provide a reliable measure of the relative degree to which banks are constrained by regulation; the sizes of a banks' capital buffers are endogenous to banks' particular circumstances, which can produce substantial variation in their targeted capital buffers (more on this below). Finally, it is important to control for cross-sectional variation in loan demand when measuring the effects of capital requirements on loan supply, which only some of the pre-existing studies of lending attempt to do.

To our knowledge, our study is the first analysis of bank-specific responses to variation in regulatory minimum capital requirements. Unlike prior studies, we can document regulatory capital requirements at the level of individual banks, and we show that these requirements vary substantially cross-sectionally and over time. Furthermore, when measuring the loan-supply response of banks to capital requirements we are able to control for contemporaneous variation in loan demand because we have access to detailed information about the composition of bank loan portfolios. Jimenez, Saurina, Ongena, and Peydro (2011) study the effects of bank-specific changes in dynamic provisioning requirements for Spanish banks. Like our study, theirs controls for demand-side influences. Changes in dynamic provisioning should be thought of as changes in the "front-loading" of capital requirements against risky assets, rather than permanent changes in capital ratio requirements. For that reason, the magnitudes of loan-supply reactions to provisioning changes should be smaller than the reactions to changes in capital ratio requirements. Thus, the findings of Jimenez et al. (2011) – which imply magnitudes of roughly half the size of those reported below – are consistent with the findings we report below.

Necessary Condition 2: Capital Requirements Must Bind

A second necessary condition for bank capital requirements to affect the loan-supply decisions of banks is that regulatory capital requirements must continuously act as binding constraints on bank capital ratio choices. If market discipline motivates banks to maintain ratios of capital far in excess of those required by regulators, then changes in regulatory requirements might have no effect on bank capital choices, and therefore, no effect on bank loan supply. Calomiris and Mason's (2004) study of credit card banks in the 1990s shows that, under some circumstances, market discipline can motivate capital ratios substantially in excess of the regulatory minimum.

When capital requirements bind, the equilibrium amount of total bank capital will still exceed the minimum requirement by a buffer chosen to minimize the costs of complying with capital requirements.[8] Empirical research has identified substantial heterogeneity with respect to bank responses to capital requirements, and particularly, the extent to which capital requirements bind on banks' choices of capital ratios. In many studies, actual capital ratios respond strongly to changes in capital requirements, but in other studies, there is little observed response, which indicates that in some circumstances market discipline may be the dominant influence on variation in capital ratios (VanHoose 2008).

For our sample of UK banks, there have been two studies examining the extent to which changes in bank-specific capital requirements affected actual capital ratios (Alfon et al (2005) and Francis and Osborne (2009)). Both studies find a substantial impact, and both conclude that capital requirements were binding on capital ratio

[8] The dynamic behaviour of buffers is a matter of some theoretical controversy. Repullo and Suarez (2009) derive a dynamic model of capital buffers under the Basel II regime. They show that the determination of risk under Basel II contributes greatly to the pro-cyclicality of capital requirements (when compared with Basel I); during recessions, capital requirements effectively rise. Thus they argue that banks will choose to hold high buffers of capital during expansions, anticipating the need for additional capital during recessions, and that this effect is so large that it is not fully mitigated by the extent of variation in macro-prudential policy. Aliaga-Diaz et al (2011) develop a dynamic optimization model to analyze the effectiveness of macro-prudential policy, based on parameters drawn from Latin American experience. They show that variation in capital requirements may have to be large to make macro-prudential policies effective. In their framework, however, anticipated reductions in capital requirements due to macro-prudential policy lead banks to endogenously choose capital buffers that are *smaller* during booms than during economic declines. That means that the countercyclical effect of capital requirement changes can be mitigated by the endogenous offsetting decisions of banks with respect to their chosen buffers. The difference between the conclusions reached by Repullo and Suarez (2009) and Aliaga-Diaz et al (2011) about the cyclical properties of capital buffers reflect differences in assumptions about the size of macro-prudential capital requirement variation over the cycle and the extent to which recessions are associated with substantial changes in risk weights on assets.

choices. In Section 2, we confirm that capital requirements appear to have been binding on bank capital decisions continuously for our sample of UK banks from 1998 to 2007. Moreover, since binding regulatory requirements are a necessary condition for capital requirement changes to affect bank credit supply, our empirical finding in Section 3 – confirming that capital requirement changes have important effects on the supply of credit – further corroborates that capital requirements were binding.

Necessary Condition 3: Limited Substitutability of Alternative Funding

The effectiveness of macro-prudential variation in regulatory capital requirements depends on limited substitutability between the credit supplied by banks that are subject to capital regulation and the financing provided by other sources not subject to minimum capital requirements. To the extent that other sources can offer substitutes for the loans of regulated domestic banks, there will be offsetting "leakages" to macro prudential policy-induced variation in the supply of loans by regulated banks. These other sources could include lending by unregulated domestic intermediaries, cross-border bank lending and securities offerings (such as commercial paper, corporate bonds or equity offerings).

The theoretical and empirical finance literature suggests that loans from intermediaries are not perfect substitutes for securities offerings. Loans involve much more detailed contracting terms than bonds – many pages that describe conditions pertaining to warranties, covenants, and collateral – which must be custom-designed for each loan contract and which require monitoring and enforcement after the loan is made.[9] Furthermore, the importance of "soft" information for limiting the screening, monitoring and enforcement costs of bank lending imply that there are limits to the ability of offshore lending to substitute for local intermediation, except in the case of very large firms that operate internationally, for whom access to local information is less relevant.[10] Thus, although "leakages" from all alternative sources of finance could potentially offset the variation in loan supply that results from macro-prudential

[9] There is a large empirical literature on the special characteristics of loans, beginning with James (1987).
[10] Evidence that local, "soft" information is relevant for most bank lending is provided in various studies, including Petersen and Rajan (2002), and Agarwal and Hauswald (2010).

regulation of affected banks, the most powerful potential substitute for regulated bank lending is lending by local intermediaries that are not subject to domestic capital regulation.[11]

The problem of "leakages" involving local intermediaries is particularly acute for an economy like the UK, which is a global financial centre. Resident foreign branches of banks headquartered abroad are not subject to FSA prudential regulation (unlike domestically headquartered banks and resident foreign subsidiaries), but are regulated by their home country regulatory authorities (which, during our period, typically set capital ratio requirements uniformly at 8% of risk-weighted assets for all banks, which was the minimum in the UK).[12] That means that if the FSA decided to raise capital requirements, foreign branches operating in the UK could be a significant source of leakage.

Regulatory leakages have understandably been of great concern to policymakers engaged in the construction of macro-prudential regimes. In the UK, for example, Paul Tucker, Deputy Governor of Financial Stability at the Bank of England, has frequently commented upon the potential problem of the "dilution" of cyclical macro prudential policies, and how this underlines the need for international co-ordination:

> Co-operation will be especially important in the deployment of 'cyclical' instruments. If one country tightens capital or liquidity requirements on exposures to its domestic economy, the effect will be diluted if lenders elsewhere are completely free to step into the gap. Basel and the EU are addressing how to handle that where the instrument is the Basel 3 Countercyclical Buffer. (Tucker (2011))

In Section 4, we investigate the extent to which Deputy Governor Tucker's concerns about dilution are warranted. Specifically, we ask whether foreign branches operating

[11] Another aspect of the UK financial system that limited the potential leakages from sources of funding other than loans on banks' balance sheets was the limited use of loan securitization during our period. Data for the UK show that, prior to 2009, loan securitization was very small in the aggregate, and that the proportion of securitized loans relative to total loans did not vary importantly at high frequency. In preliminary work, we also explored whether changes in individual capital requirements predicts greater issuance of either corporate bonds or equity in sectors that the affected bank is competing in. We did not find a statistically significant effect, which suggests that capital markets do not appear to be a significant source of leakage in our data. This is consistent with the limited substitutability between bank and bond/equity finance.

[12] Such foreign branches account for the majority of banks resident in the UK; in our sample they comprise 173 out of 277 banks. Moreover, as described in Section 4, these branches account for a non-trivial share of lending to the UK real economy, and are important in several sub-sectors of the real economy. See Aiyar (2011) for a more detailed account of the structure of the banking industry in the UK, especially relating to the difference between regulated foreign subsidiaries and unregulated foreign branches.

within the UK increase their lending to "step into the gap" when UK-regulated banks experience increases in their capital requirements. We find that this dilution effect from leakages is large and statistically significant.

In the remainder of the paper, we proceed as follows: Section 2 describes the bank-specific UK data base that we employ to measure the relationship between changes in capital requirements and changes in lending, reviews the process that governed changes in capital requirements, reports summary statistics about changes in capital requirements, and describes the relationship between capital ratio requirements and capital ratios. We also show that, despite the absence of any explicit macro-prudential mandate in FSA supervision, average capital requirements across the banking system were in fact strikingly counter-cyclical.[13]

Section 3 focuses on the connection between capital requirement changes and bank lending for the UK-resident banks that were subject to FSA capital regulation. We report regression results that demonstrate a large and statistically significant relationship between bank-specific changes in capital requirements and changes in bank lending.

Section 4 estimates the loan supply response of foreign branches operating in the UK (which are not subject to FSA capital regulations) to changes in the capital requirements imposed on UK-owned banks and resident foreign subsidiaries (which are subject to FSA capital regulation). We find evidence for large leakages, which offset about a third of the effect of capital requirement changes on the lending of UK-regulated banks. Section 5 concludes.

2 UK capital regulation, 1998-2007

Our empirical analysis of UK banks' capital ratio and lending responses to bank capital requirement changes is made possible by a regulatory policy regime that set bank-specific, time-varying capital requirements. These mimimum capital requirement ratios were set for all banks under the jurisdiction of the FSA, i.e. all UK-owned banks and resident foreign subsidiaries. Bank capital requirements are not

[13] On the other hand, this should not be entirely surprising, as the term 'macro-prudential' originated in the UK in the early 1980s (Clement, 2010).

public information. We collect quarterly data on capital requirements, and other bank characteristics, from the regulatory databases of the Bank of England and FSA. Our sample comprises 104 regulated banks (48 UK-owned banks and 56 foreign subsidiaries), and 173 unregulated foreign branches operating in the UK. Bank mergers are dealt with by creating a synthetic merged data series for the entire period. The variables included in this study are listed and defined in Table 1, and Table 2 reports summary statistics.[14]

Discretionary regulatory policy played a much greater role in the UK's setting of minimum bank capital ratios than in the capital regulation of other countries. A key focus of regulation was the so-called "trigger ratio,": a minimum capital ratio set for each bank that would trigger regulatory intervention if breached.[15] Changes in trigger ratios were communicated to the Board of Directors of the bank in a formal letter. According to Francis and Osborne (2009):

> ...the FSA inherited from the Bank of England the practice of supplementing the Basel I approach with individual capital requirements, also known as 'trigger ratios,' based on analysis of firm-specific characteristics and management practices, and this practice has been retained under Pillar 2 of Basel II. These firm-specific requirements are periodically reassessed and, where necessary, revised to reflect changing bank conditions and management practices. As part of these reviews, the FSA have considered it to be good practice in the financial services industry for a UK bank to hold an appropriate capital buffer above the individual capital ratios advised by the FSA....
>
> UK supervisors set individual capital guidance, also known as 'trigger ratios,' based on firm-specific reviews and judgments about, among other things, evolving market conditions as well as the quality of risk management and banks' systems and controls. These triggers are reviewed every 18-36 months, which gives rise to considerable variety in capital adequacy ratios across firms and over time.

The authors further note that the unique, bank-specific, discretionary UK capital regulation regime was intended to fill the gaps from the early Basel I system, which did not consider risks related to variation in interest rates, or legal, reputational and operational risks. Our empirical analysis below confirms that view; changes in

[14] The data used in this study exclude outliers based on the following criteria: (1) trivially small banks (with total loans less than £3000 on average), or (2) observations for which the absolute value of the log difference of lending in one quarter exceeded 1.

[15] The FSA also maintained a separate requirement for a "target ratio," which was set above the trigger ratio and was intended to provide a capital cushion to help prevent an accidental breach of the trigger ratio. In 2001, following the Financial Services and Market Act, the FSA stopped setting target ratios, but even before then, the trigger ratio was the primary focus of regulatory compliance.

capital ratio requirements do not appear to be associated with past or future changes in the credit risk of loans (as measured by changes in the non-performing loan ratio). Rather, cross-sectional differences in capital ratio requirements (shown in Table 3) are associated with identifiable bank-specific characteristics (size, reliance on retail deposits, sectoral loan concentration) that could proxy for a variety of other risk differences.

An implication of the view that discretionary variation of bank-specific capital ratio requirements set by the FSA reflected differences in operational and interest rate risks may explain why capital ratio requirements in excess of 8 percent were viewed as less necessary after the implementation of the Basel II system in 2007. The introduction of Basel II in 2007 generally resulted in substantial reduction in risk-weighted assets for a large number of UK banks.

When measuring the capital requirement (trigger ratio) for risk-based capital that is assigned to the individual bank, some complications arise with respect to the treatment of the "banking book" and the "trading book" of the bank. For banks that had both a banking book and a trading book (which is a characteristic of larger, more complex banks, comprising about one-third of the regulated banks in our sample), the FSA often assigned different trigger ratios for the banking and trading book, and uniformly, the trading book capital requirement is less than or equal to the trigger ratio on the banking book. When we describe capital requirements in tables and graphs, we will often refer to the "trigger ratio" and "capital requirement ratio," but we will always be referring to the banking-book trigger ratio, which is also the measure used in our regression analysis. By focusing on the banking-book trigger ratio to measure regulatory changes, our measure captures truly exogenous change, as we avoid the distortions that result from endogenous changes in the proportion of risk-weighted assets held in the trading book. It is also comparable across banks that maintain trading books and those that do not.

As Table 2 and Figure 1 shows, the variation in capital ratio requirements is large. The mean capital requirement ratio is 10.8, the standard deviation is 2.26 , the minimum value is 8%, and the maximum value is 23%. Figure 2 displays the distribution of changes in capital requirements, which are divided according to the change in the size of the capital requirements that are imposed on the banks. When defining capital requirement changes in Figure 2, and in the regression analysis

below, we exclude very small changes (changes of less than 10 basis points) which result from errors in rounding, and which are reversed in subsequent quarters.[16] Not surprisingly, there are no observed changes in capital ratio requirements of between 10 and 30 basis points. The elimination of rounding errors results in 132 remaining observations of changes in banking-book capital requirements in our sample. In general, there are more small changes in capital requirements than intermediate or large changes, although that pattern is more pronounced for UK-owned banks than foreign subsidiaries. As Figure 3 shows, most banks either experienced zero or one capital requirement change during our sample period, but 35 banks experienced two or more changes.

Figures 4, 5 and 6 plot the average capital requirement ratio for the regulated banking system, with "average" defined in three different ways, against GDP growth. Figure 4 takes a simple (non-weighted) average of the capital requirement for all regulated banks in the sample. Figure 5 weights these capital requirements by the assets of each bank. Figure 6 weights by lending to the real economy rather than by assets, and calculates the average capital requirement not directly in levels but by cumulating across *changes* in the capital requirement over successive periods; the latter is to ensure that the graph abstracts from changes in the sample of banks between time periods due to entry or exit, and only reflects changes in capital requirement ratios. All three measures are closely and positively associated with movements in GDP (the simple correlation co-efficient is 0.44, 0.52 and 0.64 respectively, in figures 4, 5 and 6 respectively). The pattern of association is stronger for weighted than for non-weighted capital requirements, although the range of variation is smaller. Average non-weighted capital requirement ratios ranged from a minimum of 10.2% in 2007 to a maximum of 11.2% in 2003.

This is a striking amount of counter-cyclical variation given that the sample period was one of varying positive growth, but no actual recessions. By way of comparison, the Basel III countercyclical buffer is to vary between 0 and 2.5% over the entire business cycle inclusive of recessions.[17] Thus, although the FSA lacked any

[16] Our method of computing the trigger ratio requires that one divide required capital by risk-weighted assets, which creates very small rounding errors that give rise to small implied "changes" in required capital ratios, which not economically significant changes.

[17] Furthermore, variation in the UK trigger ratio is a stricter embodiment of change over the cycle, given that the failure to meet the trigger ratio can have dire consequences for a bank, while a failure to meet the new Basel III countercyclical capital buffer has more limited consequences (i.e., limits on the distributions of earnings to shareholders).

explicit macro-prudential mandate over the period, the outcome of its decisions made on a bank-by-bank basis was in fact macro-prudential in nature. This provides an ideal testing ground for the likely efficacy of future explicitly macro-prudential regimes.

After 2006, around the time Basel II was introduced[18], capital requirements declined markedly, and this happened in spite of an acceleration of growth, which was contrary to the previous pattern of counter-cyclical changes in requirements. That pattern differs from the rises of prior expansionary periods, although the decline is less pronounced for weighted capital requirements than for non-weighted capital requirements (which actually fell during the 2006-2007 expansion). As noted above, the introduction of Basel II (which was designed to provide a more comprehensive measure of bank risks than the prior system) may have led to supervisors to place less reliance on discretionary setting of bank-specific capital ratios above 8 percent.

To understand the FSA's approach to setting capital requirements better, it is useful to divide the sources of variation in capital ratio requirements into three sets of factors: (1) capital requirement differences that reflect long-term cross-sectional differences in bank type, operations or condition, (2) high-frequency cross-sectional changes in bank operations or condition that capture, for example, sudden changes in bank loan quality, and (3) variation over time in average minimum capital requirements for banks that reflect what could be termed macro-prudential goals. Of these, the variation over the cycle has already been discussed above; below we document variation in the long-term cross-sectional characteristics of banks and high frequency cross-sectional changes.

In Table 3, we report summary statistics for average long-term bank characteristics and relate those to average capital ratios. The long-term bank characteristics we examine are: size, liability mix, loan write-off ratio, and concentration. Across the four quartiles of average required capital ratios, higher capital requirements are monotonically associated with smaller bank size and a smaller proportion of what could be termed "core" deposits (the sum of sight and time deposits, which excludes repos, certificates of deposit, and all non-depository sources of funding). Higher capital requirements are also monotonically increasing in sectoral concentration, defined as a bank's lending to the sector to which it has the greatest

[18] Basel II was formally introduced on January 2007 in the UK, but the transition period most likely started before that.

exposure divided by the bank's total lending.[19] With respect to loan write-offs, banks in the highest quartile of average capital requirements have substantially higher write-offs, but within the first three quartiles of average capital requirements, banks do not differ with respect to write-offs.

At high frequency—examining responses of capital requirements to quarterly changes in bank behaviour over the prior four quarters—we found practically no connection between changes in bank condition and changes in capital requirements. High-frequency changes in write-offs were negatively correlated with capital requirement changes that occurred within the same quarter, indicating that when some banks experienced large write-offs (resulting in diminished capital) regulators occasionally reduced those banks' minimum capital ratios. It is possible that high-frequency increases in write-offs are moments when supervisors believe that ongoing uncertainty about prospective bank losses has been resolved, in which case it may make sense to reduce capital requirements accordingly. This high-frequency connection between write-offs and capital requirements explained only about one percent of the panel variation in capital requirements.[20] In our regression results reported below, we further investigate whether changes in minimum capital ratio requirements are related to past or future changes in non-performing loan ratios, and we find that minimum capital ratios are orthogonal to past or future non-performing loan ratios.

Overall, therefore, we find substantial variation across banks and over time in minimum capital requirements, and we find that changes in capital requirements are correlated with long-term bank characteristics, as well as cyclical changes in economic and market conditions, but not strongly associated with identifiable high-frequency changes in banks' circumstances.

As a rough gauge of the extent to which capital requirements were binding on bank behaviour, Figure 6 plots the co-movements between weighted capital ratios and

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[19] Lending here refers to non-financial sector, non-household lending. The household sector is excluded from the measure of concentration because lending to households is not comparable in concentrating risk to lending to a particular sector. For many banks lending to households is by far the biggest individual lending category. The large size of the household sector means that a bank specializing in household lending may be well diversified *within* the sector, e.g. regionally or across different types of consumer loans, and thus less risky. At any rate, this appears to have been the view of the regulators: including household lending in the definition of concentration used here eliminates the monotonic relationship between sectoral concentration and capital requirements.

[20] If supervisors believe that write-offs resolve ongoing uncertainty about prospective bank losses, it may make sense to reduce capital requirements accordingly.

weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements. For all four groups of banks, the variation in capital requirements was associated with substantial co-movement in capital ratios, confirming the conclusions of Alfon et al (2005) and Francis and Osborne (2009) that capital ratio requirements were binding on banks' choices of capital ratios for UK banks during this sample period.

3 The effect of minimum capital requirement changes on lending by affected banks

In this Section, we estimate the effect of capital requirement changes on bank lending. Our measure of bank lending is loans to the non-financial sector. We construct that measure by aggregating all of the sectoral loan categories of a bank's lending except for its loans to financial institutions. As discussed in Section 1, changes in capital requirements should affect lending by a regulated bank only when bank equity is relatively expensive to raise, and when regulatory requirements are binding constraints.[21]

When seeking to measure the effects on bank loan supply from increased capital requirements it is important to recognize, and control for, variation in bank lending due to changes in loan demand, which is also likely to vary across banks (according to their sectoral specializations), and over the cycle. To identify loan-supply responses to capital requirement changes, in this Section, we control for loan-demand changes in several alternative ways. Following Aiyar (2011), the basic strategy is to exploit differences in the sectoral concentration of lending by different banks to identify cross-sectional differences in loan demand faced by different banks.

For *each bank*, we construct three different measures of sectoral loan demand as follows: in any quarter, each sector's total lending is measured by aggregating all lending into that sector by *other* banks in the sample. Denote that variable as Z_{iqt} ,

[21] We model the effects of capital requirement changes on loan supply. We do not model the process through which capital ratio requirements affect capital ratios, although our estimation of loan-supply effects does allow banks with different "buffers" between minimum and actual capital ratios to respond differently to increases in capital requirements. We focus on loan-supply effects for two reasons: First, loan-supply is the primary variable of interest. Second, as we discuss further below, buffers vary substantially and persistently across banks, and banks with relatively large buffers tend to exhibit *greater* responsiveness to capital ratio requirement changes, not less. Heterogeneity in buffers likely reflects unobservable bank characteristics associated with the costs of raising capital.

where t indexes the quarter, q indexes the sector and i indexes the bank for which it is constructed. Allowing small-case letters to denote logs, Δz_{iqt} represents percentage changes in sectoral lending thus constructed. Then we aggregate across sectors, weighting the change in lending in each sector by that sector's importance to bank i; thus $z_{it} = \sum_q s_{iqt-1} \Delta z_{iqt}$, where s_{iqt} denotes the share of sector q in bank i's lending portfolio in period t.

The variable z_{it} serves as our first measure of *bank-specific* loan demand. However, the measure is imperfect because growth in aggregate lending by all other banks may still reflect the common supply-side effect of macro-prudential policy. We construct two additional measures designed to address that problem. First, for each sector we simply subtract total (non-sectorally weighted) bank lending growth for all banks from the bank-specific measure $z_{it.}$ This subtraction should remove supply-side influences that are common to both total bank lending and sectorally-weighted bank lending, leaving only the bank-specific weighted sectoral deviations of loan growth, which should reflect demand-side influences. We call this measure "adjusted z". Our second approach is to regress z_{it} on the time series average (asset-weighted) change in bank capital requirements. The bank-specific time series residual from that regression is a proxy for loan demand growth faced by that particular bank. We call this measure "residual z".

Thus the general specification is:

$$\Delta l_{it} = \alpha_i + \sum_{k=0}^{3} \beta_{t-k} \Delta KRR_{it-k} + \sum_{k=0}^{3} \gamma_{t-k} z_{it-k} + X\Pi + \varepsilon_{it}$$

where Δl_{it} denotes lending growth in period t by bank i, ΔKRR_{it} denotes the change in the capital requirement ratio, α_i is a bank-specific fixed effect, and X is a vector of controls. z_{it} is the demand proxy discussed above, in any of its three varieties.

Both the contemporaneous change in capital requirements and three lags are included in the equation. On the basis of regulatory data we only observe a change in the capital requirement when the trigger ratio in a particular report differs from the trigger ratio in the preceding report from three months earlier; we do not know when,

within that three month period, the change in capital requirements was introduced. Moreover, it is possible that FSA regulators—who maintain an ongoing dialogue with the banks they supervise—might inform a bank in advance of a forthcoming change in the capital requirement ratio. Both these considerations indicate the necessity for a contemporaneous term of the dependant variable in addition to lags.

Table 4a reports five versions of our baseline loan-supply regressions. All specifications are estimated in a panel fixed-effects framework, where the bank-specific fixed effect should capture heterogeneity in lending growth arising from relatively long-run, time-invariant bank characteristics.[22] The first column does not include any controls. The second column introduces the raw value of z as a control, together with the standard macroeconomic variables used as controls in other studies, GDP growth and inflation.[23] The third and fourth columns substitute the raw value of z with, respectively, the adjusted z and residual z demand proxies discussed above. The fifth column introduces bank-specific characteristics as additional controls. Specifically, we include TIER1, RISK, SUB, and BIG. TIER1 is Francis and Obsborne's (2009) measure of a bank's low cost of equity capital relative to other banks (which is revealed by its relatively high dependence on tier 1 capital). RISK is a measure of the riskiness of bank assets: the ratio of risk-weighted assets to total assets. SUB is an indicator variable that captures whether the bank is a subsidiary of a foreign bank. BIG is an indicator variable that captures whether the bank has assets in excess of £10 billion.

We find that loan supply responds negatively to increases in capital requirements. The parameter of interest is tightly estimated across the full range of specifications. Summing across lags of the change in the capital requirement ratio yields estimates between 0.065 and 0.072.That is, an increase in the capital requirement ratio of 100 basis points induces, on average, a cumulative fall in lending

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

[23] A key macroeconomic variable that could potentially affect lending growth is monetary policy, and indeed, there is a rich literature documenting this effect, such as the seminal Kashyap and Stein (2000). We have experimented extensively with including monetary policy as an explanatory variable, but because of the subtlety of the issues raised, in particular, possible interactions between monetary policy and changes in regulatory capital requirements, we defer these results to a separate forthcoming working paper (Aiyar, Calomiris and Wieladek (2011)). Here we note only the most pertinent finding from that work: while we find, in conformity with the literature, that monetary policy affects bank lending, its impact appears to be orthogonal to the impact of regulatory capital requirements.

growth of between 6.5 and 7.2 percentage points.[24] Higher GDP growth is unsurprisingly associated with more rapid lending growth, while the (sector-based) demand controls are insignificant, suggesting that demand conditions tend to vary quite uniformly across sectors. Bank-specific balance sheet characteristics used as controls in other studies (TIER1, RISK, SUB, and BIG) are not significant.

Two separate concerns regarding endogeneity arise for the specifications in Table 4a. First, the relationship of interest might be subject to reverse causality. The bank regulator could be responding to overly rapid loan growth by increasing the responsible bank's minimum capital requirement. However, if this were the case, our results for the responses of loan supply are even stronger than reported, because such behaviour by the regulator would tend to generate a *positive* co-efficient between loan supply and changes in capital requirements.

Second, and of perhaps greater import, underlying changes to the quality of the bank's loan portfolio could be driving both regulatory changes in minimum capital ratios and changes in credit supply, thereby generating a spurious correlation between the latter two variables. To address this potential problem we examined the contemporaneous correlation between a proxy for loan quality—write-offs—and minimum capital requirements, and found none. Moreover, we found that the change in capital requirements for a bank cannot be predicted by contemporaneous, lagged, or future values of changes in write-offs. This suggests that poorly performing loan books are not the main driver behind changes in capital regulatory requirements. While banks which have relatively high write-offs over the whole time-series on average have higher minimum capital requirements than banks which have relatively low write-offs (as shown in Table 3), this systematic difference applies only to the cross-section.

Of course, it may still be the case that changes in loan quality affect loan supply for reasons unrelated to capital requirements, and indeed, we find evidence that this is the case in our sample. Table 4b shows the same regressions as Table 4, but with contemporaneous and lagged values of changes in write-offs introduced as additional explanatory variables. If deteriorating loan books were driving both changes in capital requirements and changes in credit supply, then we should find that

[24] Strictly speaking, the cumulative impact on lending growth will differ from these estimates due to compounding.

the coefficients on the regulatory changes become insignificant, or diminish in magnitude. In fact, the coefficients on capital requirement changes are almost identical to those in Table 4, suggesting that changes in write offs and changes in miminum capital ratios are orthogonal. We do find, however, that deteriorating loan portfolios exercise a negative impact on credit supply (columns 4 and 5), but that impact is independent of the impact of regulatory changes.

It is also possible that regulators change capital requirements in anticipation of *future* deterioration in loan portfolio quality (and that banks reduce credit supply motivated by the same anticipation). Table 4c accordingly shows the same regressions as Table 4b, but with contemporaneous and *leading* values of changes in write-offs (rather than lags) introduced as additional explanatory variables. But the impact of leads of write-offs on credit supply is statistically insignificant, while the impact of regulatory capital changes remains robust.

As a further robustness check, we estimated, but do not report, the specifications in Table 4a with time dummies instead of macroeconomic controls. The coefficient magnitudes on the capital requirement ratio variable were qualitatively very similar. We also experimented with an autoregressive version of the specification above, while omitting fixed effects. Using fixed effects in an autoregressive framework introduces bias via the correlation between the lagged dependent variable and the fixed effects. While this could in principle be addressed using GMM techniques, the instrumentation schemes tend to be very data intensive, and we believe are not appropriate for the sample studied here.[25] Instead we follow recent empirical contributions, such as the one-step procedure in Kashyap and Stein (2000) and the internal capital markets specifications in Cetorelli and Goldberg (2008), in omitting fixed effects in these specifications, using random effects instead. Again, the results are very similar qualitatively.

[25] GMM techniques are most useful in "large N, small T" settings. Under Difference and System GMM (Arellano and Bond (1991), Blundell and Bond (1998)), the instrument count is quartic in the time dimension, which in our case numbers slightly under 40 periods (relative to 104 regulated banks in the sample). A large set of instruments leads to biased estimates through overfitting endogenous variables. Roodman (2000) suggests as a rule of thumb that the number of instruments should never outnumber the panel's individual units, and simulations indicate considerable bias even in the presence of much smaller instrument sets relative to the number of panel units. Moreover, since the number of elements in the estimated variance matrix of the moments is quadratic in the instrument count, it is quartic in T. So a finite sample is unlikely to contain adequate information to estimate the matrix well for large T.

In a recent paper on fiscal policy, Romer and Romer (2010) argue that their 'narrative' measure of tax changes is exogenous with respect to output. They use both a single equation approach, under the assumption that their tax measure is exogenous, and a VAR, assuming that output and their measure are jointly endogenous, to estimate the effect of changes in taxes on output. Based on the finding that estimates from both methods are very similar, they conclude that their measure is indeed exogenous with respect to output. We followed a similar procedure and estimated a panel VAR to assess endogeneity is a serious problem in our application. These results are presented in appendix B. In general, of course, coefficient magnitudes from the single equation specifications reported here and the panel VAR will be different. But, in the absence of endogeneity bias, conditional on a correct VAR identification scheme, and other conditions (discussed in more detail in Appendix B), the VAR and single-equation results should be similar. As we show in appendix B, all of these restrictive conditions appear to be met since the cumulative value of the lending growth impulse response to a capital requirements shock is 4.6%, similar to the single equation cumulative sum of coefficients of about 6.4%. This suggests that the restrictive assumptions necessary for the single equation model to provide an unbiased estimate of the change in capital requirement on lending growth do not appear to be rejected by data.

In the absence of strong instrumental variables, of course, it is not possible to definitively rule out endogeneity. However, the fact that our results are robust to leads and lags of writeoffs, along with the striking similarity between the panel VAR and single-equation estimates, suggest that the estimates presented in Tables 4-6 are likely not contaminated by serious endogeneity bias.

Table 5 looks more carefully at the role played by the capital buffer, and by bank size, by introducing a term interacting the change in the capital requirement with dummy variables for, respectively, banks in the lowest quartile of buffer size, banks in the lower half of buffer size, banks in the highest quartile of bank size and banks in the upper half of bank size. Column 1 suggests that the response of a bank in the first quartile of capital buffers—i.e. a bank which has an average (over time) capital buffer which is "low" relative to other banks—to a change in capital requirements is *smaller* than the response of a bank which is not in this quartile. This effect is not statistically

significant. But, as shown in column 2, there *is* a significant difference in the responsiveness of banks which have an average capital buffer below that of the median bank.

This finding is consistent with recognizing the endogeneity of capital buffers to bank-specific characteristics. Banks with relatively easy access to capital markets choose to hold smaller buffers, and have a smaller loan supply response to changes to capital requirements. On the other hand, banks which find it difficult to access capital markets choose to hold larger buffers and also have a larger loan supply response to changes in capital requirements. These results are analogous to a well-known phenomenon in the investment literature: firms with larger cash holdings exhibit greater cash flow sensitivity of investment, and even greater cash flow sensitivity of cash (Calomiris, Himmelberg, Wachtel (1995), Almeida, Campello and Weisbach (2004), Acharya, Almeida and Campello (2006)). Moreover, as illustrated by columns 3 and 4, it appears that bank size is a (noisy) indicator of capital buffers, with larger banks tending to hold smaller capital buffers and vice-versa.[26]

Columns 3 and 4 of Table 5 show no statistically significant difference in the responsiveness of loan supply by banks in the upper quartile of the size distribution. This result is somewhat surprising, since one would expect larger banks to find it less expensive to raise capital, and thus to reduce loan supply less in response to an increase in capital requirements. In forthcoming work (Aiyar, Calomiris and Weiladek (2012)) we find that, in some specifications, particularly when monetary policy and capital requirement changes are modelled simultaneously, size interactions can matter for the responsiveness of loan supply to capital requirement changes. Thus, the "rejection" of size effects in Table 5 is not robust to more complicated specifications of the policy environment.

Finally, it is worth noting that while we have presented strong evidence that banks react to stricter capital requirements by adjusting credit supply, a regression of changes in actual (nominal) capital on changes in the capital requirement ratio finds no significant relationship. So it appears as though banks change their capital to risk-

[26] This finding is consistent with (although not equivalent to) evidence that larger banks tend to hold less capital in a large cross-country sample of banks (Cihak and Schaek (2007)).

weighted assets ratio in response to regulatory tightening by adjusting the denominator rather than the numerator.

4 Leakages associated with foreign branches

In Section 3, we showed that UK-regulated banks exhibit a strong loan-supply response to changes in required capital ratios. Here we explore the extent to which those loan-supply effects are mitigated by endogenous loan-supply decisions by foreign branches operating in the UK, which are not subject to domestic UK capital regulation. As noted in Section 1, such branches may "step into the gap" created by macro-prudential policy; when capital-regulated banks contract their loan supply, unregulated banks operating in the UK may offer substitute sources of credit to borrowers.

As Figure 7 shows, the aggregate amount of lending by foreign branches is substantial, although smaller than the aggregate amount of lending by banks that are subject to UK capital regulation. Moreover, branch lending is not confined to one or two sectors, but is rather broad-based. In four sectors lending by branches accounts for 40% or more of total sectoral lending.

Our empirical strategy is to regress foreign branch lending growth on the instrumented lending of a "reference group" of regulated banks. The instrument is the change in capital requirements that occurred for that reference group. We report results for reference groups defined alternatively as the entire set of regulated banks, or as a branch-specific reference group weighted by the sectoral exposures of the branch. As before, we use the "residual of z" to proxy for loan demand.

Thus the specification is:

$$\Delta l_{jt}^{BRN} = \alpha_j + \sum_{k=0}^{3} \beta_{t-k} \Delta l_{jt-k}^{REF} + \sum_{k=0}^{3} \gamma_{t-k} z_{jt-k} + X\Pi + \varepsilon$$

where Δl_{jt}^{BRN} denotes lending growth by the foreign branch j and Δl_{jt}^{REF} denotes lending growth by branch j's reference group of regulated banks. Note that j indexes branches, while i is reserved to index regulated banks. Δl_{jt}^{REF} is instrumented using

several lags of ΔKRR_{jt}^{REF}. And both Δl_{jt}^{REF} and ΔKRR_{jt}^{REF} come in aggregate and branch-specific varieties, whose precise construction is described below.

Let $\tilde{z}_{qt}$ denote the log of aggregate lending by all regulated banks to sector q in period t. Then the *aggregate variety* of Δl_{jt}^{REF} is constructed as: $\Delta l_{jt}^{REF} = \sum_q \Delta \tilde{z}_{qt}$, and the *branch-specific variety* is constructed as: $\Delta l_{jt}^{REF} = \sum_q s_{jqt-1} \Delta \tilde{z}_{qt}$. Note that the aggregate variety of Δl_{jt}^{REF} is identical for all branches.

The *aggregate variety* of ΔKRR_{jt}^{REF} is simply defined as: $\Delta KRR_{jt}^{REF} = \sum_i \sigma_{it-1} \Delta KRR_{it}$, where σ_{it} denotes economy-wide lending by bank i as a share of economy-wide lending by all regulated banks in period t. Again, note that the aggregate variety of ΔKRR_{jt}^{REF} is identical for all branches.

Let $\Delta KRR_{qt} = \sum_i \sigma_{iqt-1} \Delta KRR_{it}$ where σ_{iqt} denotes lending by bank i to sector q as a share of lending by all regulated banks to sector q in period t. This is a measure of the sector-specific change in capital requirements in each period. Then the *branch-specific variety* of ΔKRR_{jt}^{REF} is defined as: $\Delta KRR_{jt}^{REF} = \sum_q s_{jqt-1} \Delta KRR_{qt}$.

Note that Δl_{jt}^{REF} is defined in terms of weighted *changes* in regulated bank lending, and that the weights—the sectoral exposure pattern of the branch—are taken for the *previous* period. This is to ensure that that Δl_{jt}^{REF} reflects actual changes in lending by relevant regulated banks, rather than simply changes in the sample of regulated banks across time periods (because of entry or exit of some regulated banks from the sample). Identical considerations apply to the construction of ΔKRR_{jt}^{REF}.

Again, both the contemporaneous term and lags of the independent variable of interest—reference group lending—are included in the specification. If banks are made aware by the FSA of an impending increase in capital requirements, those banks are in turn likely to inform loan customers of an intent to contract lending (e.g. by reducing or eliminating lines of credit as they mature). Bank borrowers, therefore,

may seek new lending relationships that begin simultaneous with the contraction in loan supply induced by changing capital requirements.

The instruments we use have considerable intuitive appeal in this application. We have shown in the previous section that lending by regulated banks responds strongly to changes in capital requirements. Moreover, it is hard to imagine any channel through which changes in capital requirements could affect lending by unregulated banks except *via* the impact on lending by regulated banks.

Table 6 presents results from instrumental variables regressions. Columns 1 through 3 report results using the aggregate reference group of all regulated banks, while columns 4 through 6 report results from using a branch-specific reference group as described above. Columns 1 and 4 include no controls. Columns 2 and 5 include our preferred "residual z" demand control. Columns 3 and 6 include, in addition, GDP growth, inflation, and three branch-specific variables: SIZE, KAR and WHL.[27] SIZE is the log of the bank's total assets. KAR is a measure of leverage, the capital asset ratio. WHL is a measure of reliance on wholesale funding, being the ratio of repo liabilities to total liabilities.

We find that lending by foreign branches is strongly negatively related to instrumented lending by the foreign branch's reference group. That is, a reduction in loan supply by regulated banks in response to tighter capital requirements indeed induces an increase in loan supply by unregulated foreign branches. The result on leakages holds for both the broad and narrow reference group specifications, but the results are, unsurprisingly, stronger for the branch specific reference group. Table 6 also reports a set of post-estimation statistics. The Sargan-Hansen test of overidentifying restrictions indicates that capital requirements weighted by branch-specific sectoral exposures are much better instruments than the unweighted change in capital requirements. Conventional tests for weakness of instruments—for example comparing the Kleibergen-Paap Wald F-statistic against critical values for an "acceptable" level of bias—are not possible, because the relevant critical values have

[27] Foreign branches do not file the BSD3 report on capital adequacy which we used to construct the bank-specific balance sheet controls in Table 4. But they are required to report (less detailed) balance sheet data using the BT form, which are used to construct the control variables here.

not been tabulated.[28] However, to assuage concerns about weak instruments, we report two tests for robust inference in the presence of weak instruments.[29]

What do these numbers say about the magnitude of leakages from prudential regulation? The simple average of the coefficients estimated in the branch-specific specifications 4 through 6 is 2.67. That is, the cumulative impact of a *capital requirement-induced* reduction of 1% in lending growth by regulated banks is an increase in lending growth of 2.67% by foreign branches. As noted earlier, regulated banks are, on average, much bigger than foreign branches and lend more into the real economy. Across the sample, quarterly lending by the average regulated bank was £9.5 million, about 15 times larger than quarterly lending by the average foreign branch, which stood at £630,000. On the other hand, there are more foreign branches (173) in our cross section than regulated banks (104). The product of these ratios between branches and regulated banks yields a rough estimate of leakages. Thus, over our sample period, the regulatory leakage from foreign branches amounted to just under one-third: 29.4% = (2.67*(63/950)*(173/104)*100).

It appears, therefore, that over the sample period leakages from non-UK regulated banks operating in the UK were qualitatively and quantitatively important.[30] Leakages substantially reduced, but did not fully offset, the contractionary credit-supply impact of a tightening in capital requirements. The estimates reported here likely represent a lower bound on the size of total regulatory leakages, which could also occur through cross-border lending or via capital markets, but, as noted earlier, there are good reasons for believing that foreign branch lending comprises the major element of such leakages. This evidence validates the focus on reciprocal arrangements between financial regulators to prevent leakages from forthcoming

[28] See Stock and Yogo (2002). The authors tabulate critical values for various combinations of number of endogenous regressors and number of instruments.

[29] Results are given for the Anderson-Rubin Wald test and Stock-Wright S test. The null hypothesis tested in both cases is that the coefficients of the endogenous regressors in the structural equation are jointly equal to zero, and, in addition, that the overidentifying restrictions are valid. Both tests are robust to the presence of weak instruments. The tests are equivalent to estimating the reduced form of the equation (with the full set of instruments as regressors) and testing that the coefficients of the excluded instruments are jointly equal to zero (see Stock, Wright and Yogo (2002) for further discussion). Both tests indicate rejection of the null across all specifications.

[30] As a robustness check we also estimated the "leakage" regressions in reduced form, i.e., we estimated various specifications in which lending by branch j is regressed directly on contemporaneous and lagged values of changes in the reference group's minimum capital requirement. These results support the instrumental variables results noted here.

macro-prudential regimes, e.g. the reciprocity principle enshrined in the Basel III counter-cyclical capital buffer.

5 Concluding Remarks

We consider the consequences for bank credit supply of macro-prudential capital regulation, using a unique UK "policy experiment" (the practice of setting bank-specific, time-varying capital requirements) to gauge the potential effectiveness of macro-prudential changes in bank capital requirements. We employ data on individual banks operating in the UK from 1998 to 2007.

For macro-prudential policy to be effective in controlling the aggregate amount of lending in an economy, three necessary conditions must be satisfied: (1) it must be relatively costly to raise equity capital, (2) regulatory capital requirements must bind on banks, and (3) macro-prudential "leakages" – substitutes for regulated banks' lending – must not be able to fully offset the loan-supply effects of variation in capital requirements. The UK evidence suggests that all three conditions were satisfied.

Banks that were subject to UK capital regulation display large and statistically significant responses in their loan-supply behaviour to changes in regulatory capital requirements. The loan-supply behaviour of banks that were not subject to UK capital requirements – foreign bank branches operating in the UK – responded to increases in UK capital requirements by increasing their loan supply, even as regulated banks contracted lending. This leakage was large, amounting to about a third of the aggregate change in loan supply that otherwise would have resulted. That conclusion reinforces the need for macro-prudential regulators to coordinate changes in capital requirements to prevent regulatory arbitrage by banks that can avoid domestic bank regulation.

Our estimates of the effects of changes in capital requirements on lending supply to the real economy may seem large, especially when compared to recent estimates of this effect produced by the Bank of International Settlements (2011).[31]

[31] We estimate an elasticity of loan supply for regulated banks with respect to the minimum capital ratio requirement of roughly negative one, and the net effect (after taking account of foreign branches' partially offsetting response) is two-

But the BIS study is based on macroeconomic data. The econometric identification of loan-supply responses is much more challenging in a macroeconomic context. Macroeconomic aggregates would be affected by the leakages via foreign branches analyzed in our study. They would also be affected by other potential regulatory leakages, resulting in a smaller net effect on loan supply from any change in capital requirements. Our results are therefore not necessarily inconsistent with estimates from macroeconomic data, but they are more precise in delineating how individual responses to regulatory change lead, in the aggregate, to changes in system-wide credit supply. Our findings also emphasize that the effect of capital requirements on aggregate lending may become stronger once the reciprocity agreement embedded in Basel III becomes enforced and the branch leakage documented in this paper is eliminated.

Finally, our results—based on the 1998-2007 UK sample—should not be interpreted as providing a definitive measure of the size of loan-supply responses by regulated banks, or leakages from other banks, either in the future for the UK, or in other countries. The extent to which foreign branches constitute a leakage depends upon their relative size, which has been growing over time in the UK. Furthermore, differences across countries in the structure of their financial systems are likely to play a fundamental role, as well, both for the loan-supply responses of regulated banks and the relevant sources of leakage from other lenders.

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thirds of that. These large magnitudes are consistent with another observation noted in our study: that capital does not increase when capital ratio requirements are raised.

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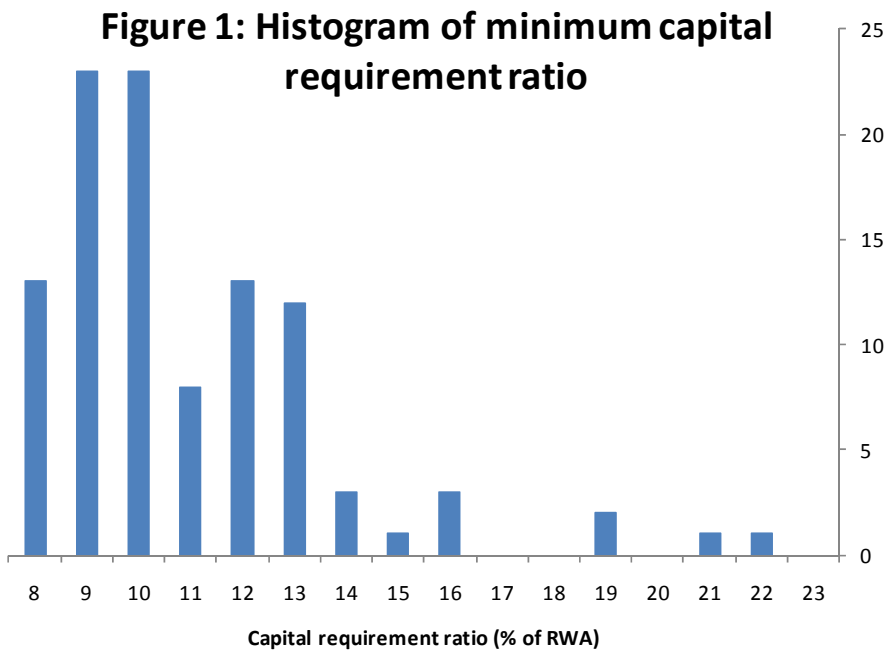
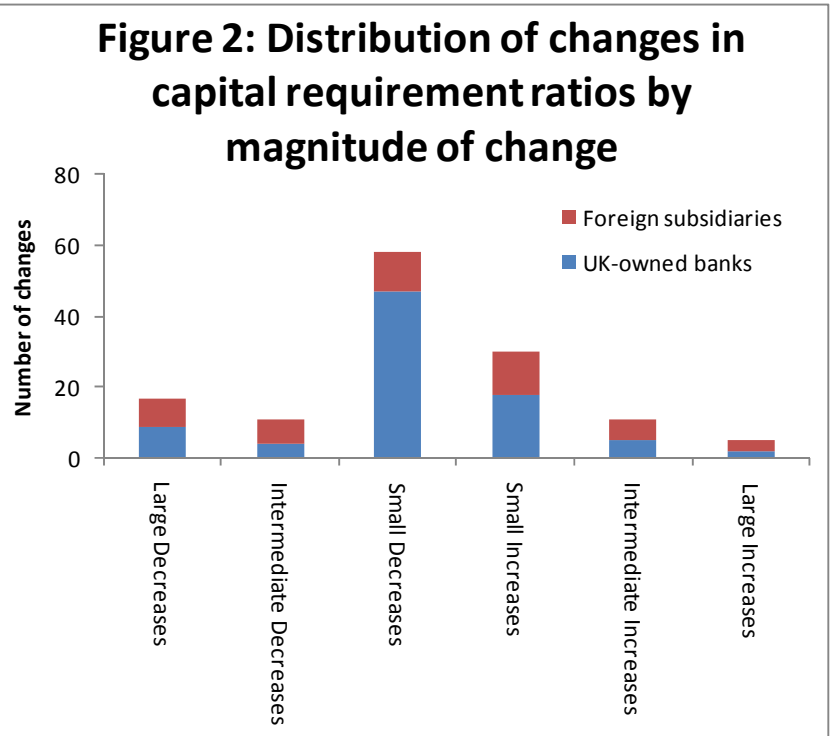
Appendix A: Charts and Tables





Large decrease = DKR<-150bp
Intermediate decrease = -150bp<DKR<-100bp
Small decrease = -100bp<DKR<-10bp
Large increase = DKR>150bp
Intermediate increase = 150bp>DKR>100bp
Small increase = 100bp>DKR>10bp

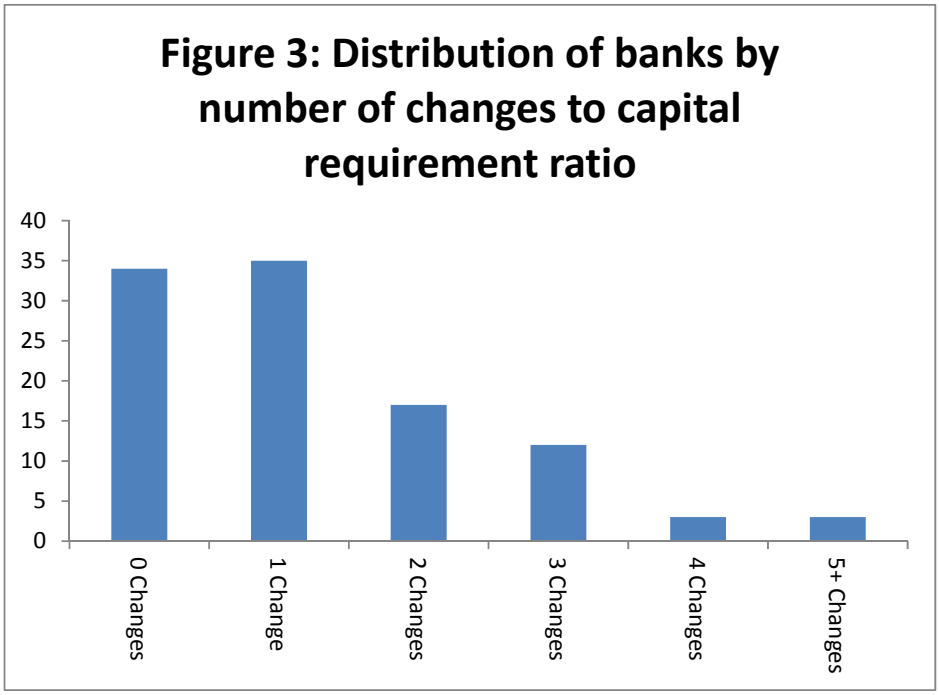


Figure 3: Distribution of banks by number of changes to capital requirement ratio
40
35
30
25
20
15
10
5
0
0 Changes
1 Change
2 Changes
3 Changes
4 Changes
5+ Changes

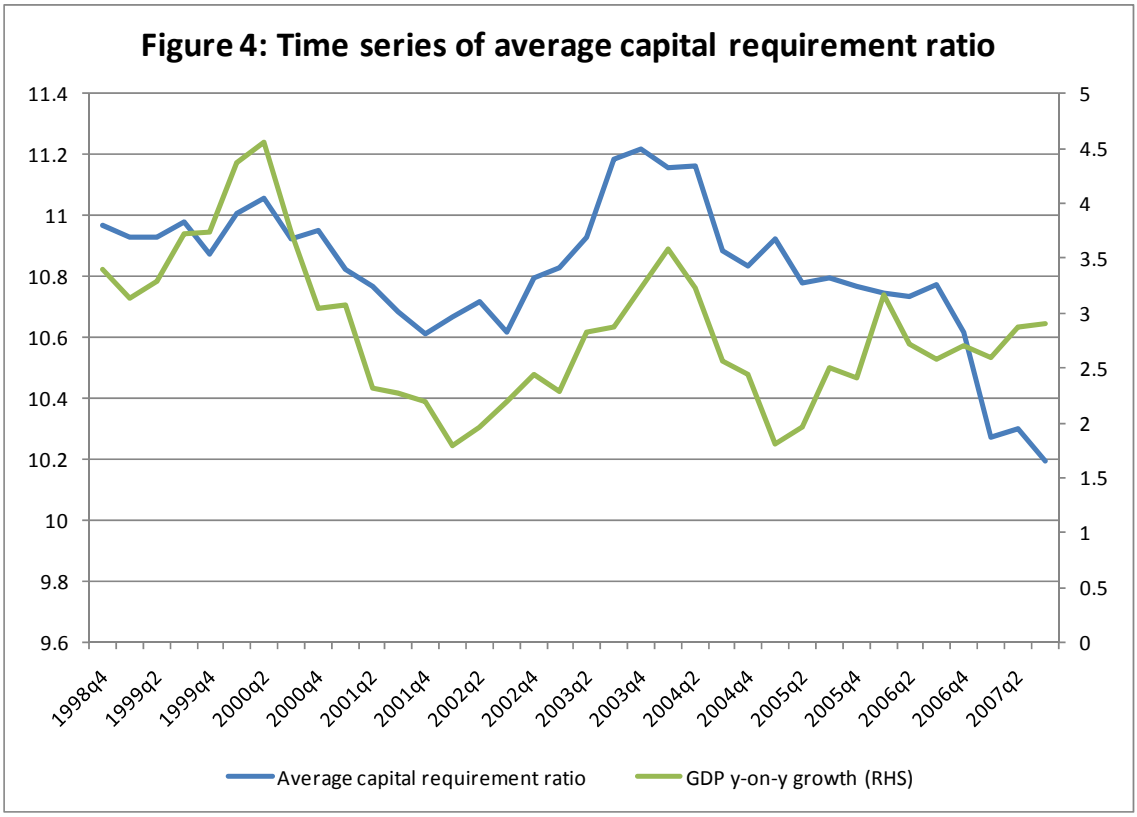


Figure 4: Time series of average capital requirement ratio
11.4
11.2
11
10.8
10.6
10.4
10.2
10
9.8
9.6
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1998q4
1999q2
1999q4
2000q2
2000q4
2001q2
2001q4
2002q2
2002q4
2003q2
2003q4
2004q2
2004q4
2005q2
2005q4
2006q2
2006q4
2007q2
Average capital requirement ratio
GDP y-on-y growth (RHS)

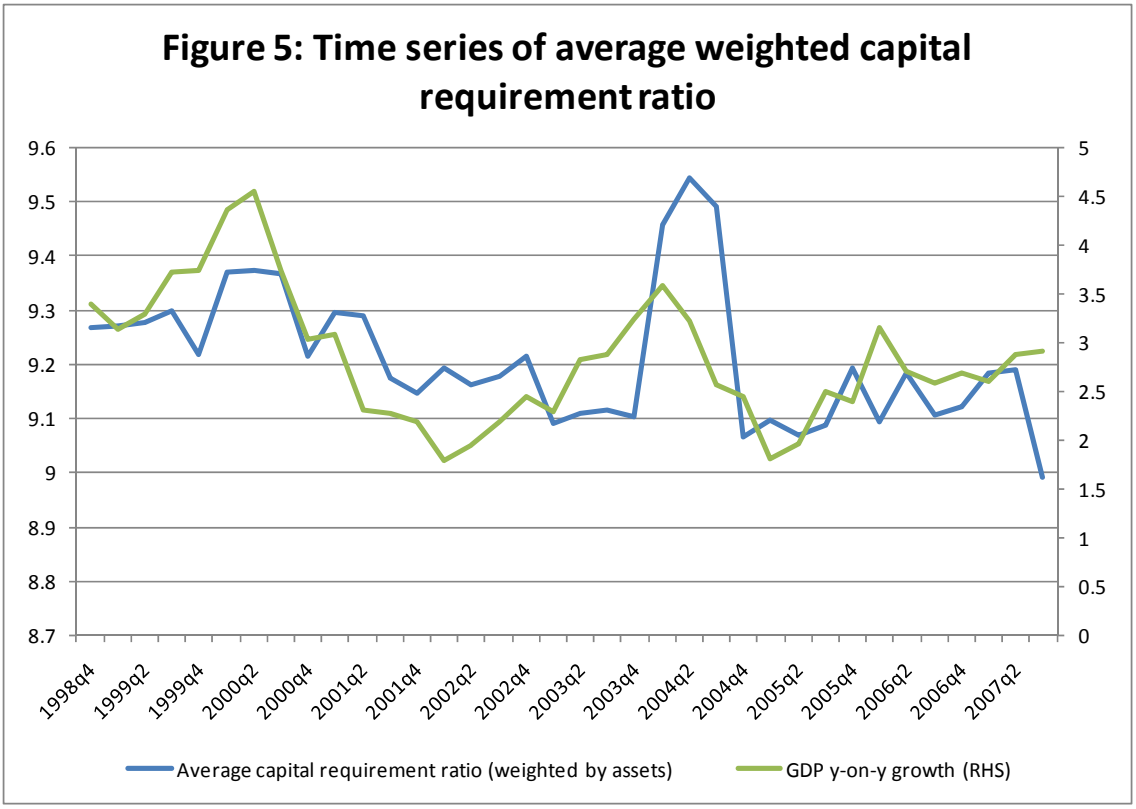


Figure 5: Time series of average weighted capital requirement ratio
9.6
9.5
9.4
9.3
9.2
9.1
9
8.9
8.8
8.7
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1998q4
1999q2
1999q4
2000q2
2000q4
2001q2
2001q4
2002q2
2002q4
2003q2
2003q4
2004q2
2004q4
2005q2
2005q4
2006q2
2006q4
2007q2
Average capital requirement ratio (weighted by assets)
GDP y-on-y growth (RHS)

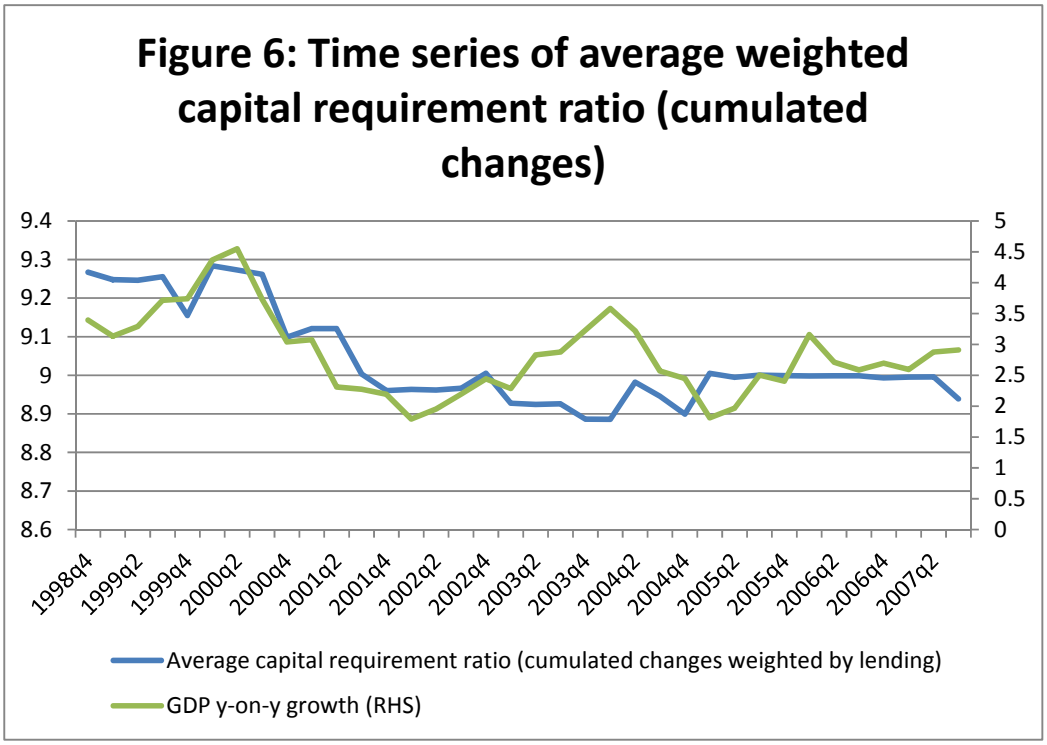
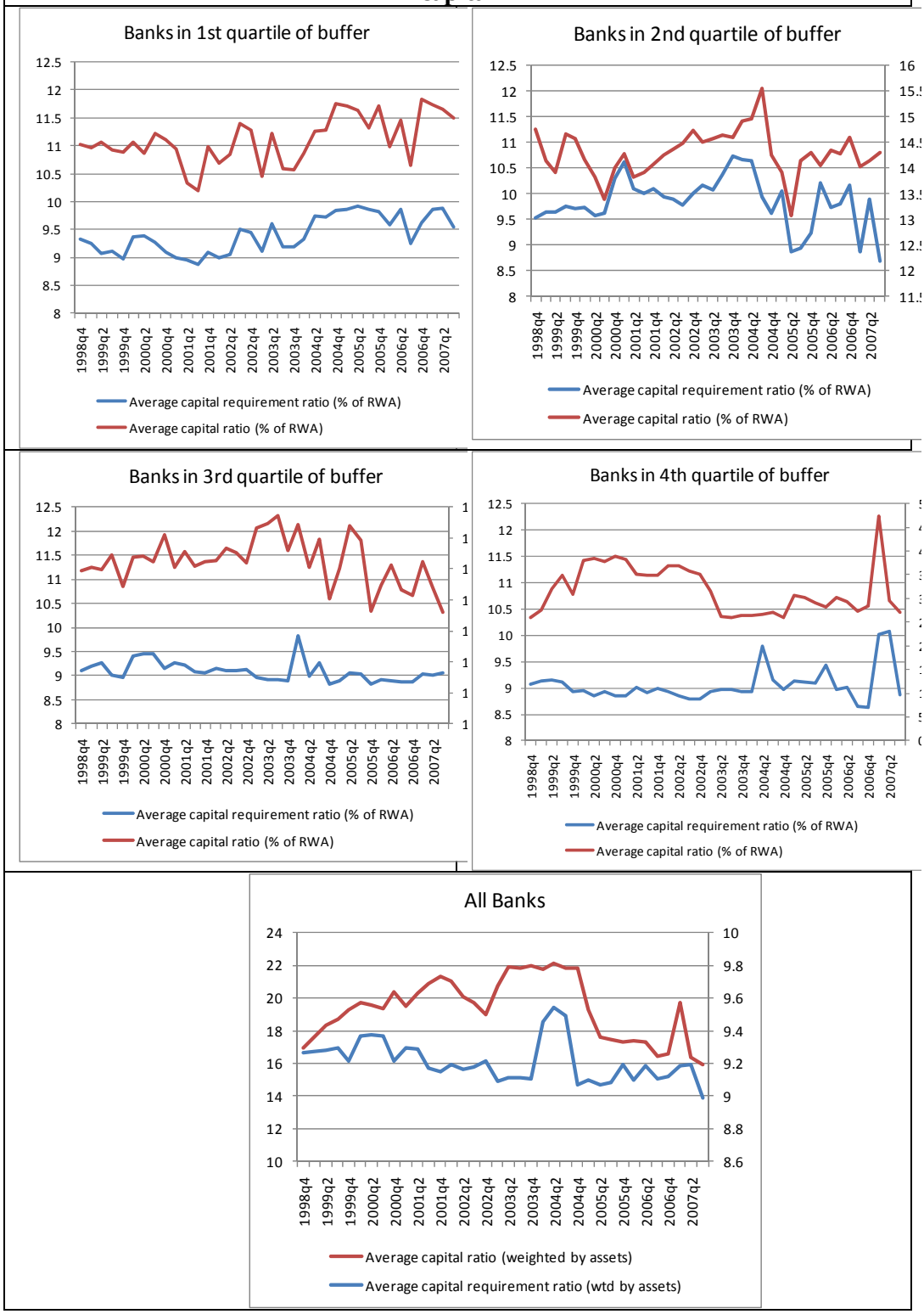


Figure 6: Time series of average weighted capital requirement ratio (cumulated changes)
9.4
9.3
9.2
9.1
9
8.9
8.8
8.7
8.6
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1998q4
1999q2
1999q4
2000q2
2000q4
2001q2
2001q4
2002q2
2002q4
2003q2
2003q4
2004q2
2004q4
2005q2
2005q4
2006q2
2006q4
2007q2
Average capital requirement ratio (cumulated changes weighted by lending)
GDP y-on-y growth (RHS)

Figure 7: Co-variation between average capital requirements and average capital



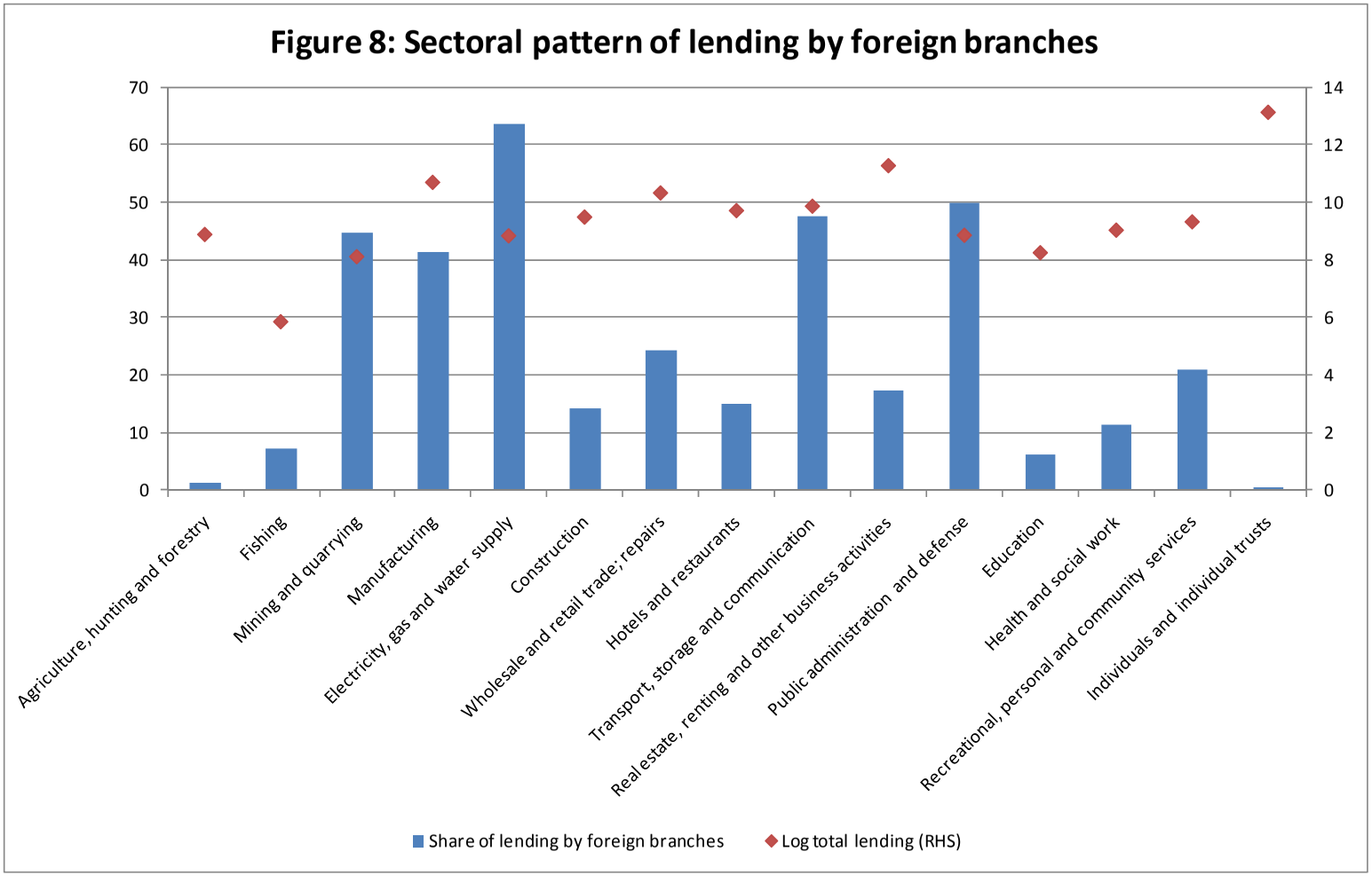


Figure 8: Sectoral pattern of lending by foreign branches
70
60
50
40
30
20
10
0
14
12
10
8
6
4
2
0
Agriculture, hunting and forestry
Fishing
Mining and quarrying
Manufacturing
Electricity, gas and water supply
Construction
Wholesale and retail trade; repairs
Hotels and restaurants
Transport, storage and communication
Real estate, renting and other business activities
Public administration and defense
Education
Health and social work
Recreational, personal and community services
Individuals and individual trusts
Share of lending by foreign branches
Log total lending (RHS)

Table 1: Variables and data sources

Variable	Definition	Source (Bank of England Reporting Form)	Notes
Capital requirement ratio	FSA-set minimum ratio for capital-to-risk weighted assets (RWA) for the banking book. Also known as "Trigger ratio".	BSD3	
Lending	Bank lending to non-financial sectors of the economy	AL	
TIER1	Ratio of Tier 1 capital to RWA.	BSD3	
SIZE	Total assets	BSD3 / BT	BSD3 for regulated banks; BT for foreign branches.
BIG	Dummy variable = 1 when SIZE is in highest decile.	BSD3	
RISK	Ratio of RWA to total assets.	BSD3	
SUB	Dummy variable = 1 when bank is a resident subsidiary of a foreign bank.		Information from the Bank of England's Monetary and Financial Statistics Department.
BUF	Difference between actual capital and the capital requirement ratio, divided by RWA.	BSD3	
KAR	Capital asset ratio	BT	
WHL	Ratio of repo liabilities to total liabilities	BT	

Table 2: Summary Statistics

Variable	Entity	Units	Mean	SD	Min	Max	Obs
Capital requirement ratio	Regulated banks	%	10.8	2.26	8	23	2,630
Change in capital requirement ratio	Regulated banks	Basis points	-1.4	29.7	-500	500	2,524
Lending to real economy	Regulated banks	£ million	9,483	28,510	0	274,140	2,630
Lending to real economy	Foreign branches	£ million	630	893	0	10,175	3,976
Change in lending to real economy	Regulated banks	%	0.8	16.5	-98.3	85.3	2,503
Change in lending to real economy	Foreign branches	%	0.3	20.9	-98.7	98.4	3,792

Table 3: Average capital requirement ratio by various bank attributes 1/

	Percentiles			
Variable	25 <	25-50	50-75	> 75
Writeoffs 2/	10.36	10.44	10.15	11.57
(Mean value within quartile)	(0.00)	(0.13)	(0.48)	(2.48)
Size 3/	12.30	11.06	10.63	9.54
(Mean value within quartile)	(0.03)	(0.10)	(0.32)	(5.16)
Retail Deposits 4/	12.45	10.79	10.08	10.21
(Mean value within quartile)	(3.0)	(15.4)	(44.3)	(73.6)
Sectoral Specialisation 5/	10.51	10.87	10.90	11.25
(Mean value within quartile)	(16.1)	(39.4)	(59.3)	(89.4)

1/ The mean values of the variables within each quartile are provided in brackets below the associated mean capital requirement.
2/ Defined as total amount written-off as a share of risk-weighted assets.
3/ Defined as asset size relative to total assets of the banking system.
4/ Defined as the sum of sight and time deposits as a fraction of total liabilities.
5/ Defined as lending to the sector to which the bank has the greatest exposure in percent of total lending by the bank to all non-financial non-household sectors.

Table 4a: The impact of minimum capital requirements on bank lending 1/
Dependant variable: Rate of growth of lending

	1	2	3	4	5
Change in capital requirement ratio (summed lags)	-0.0676***	-0.0645***	-0.0657***	-0.0684**	-0.0716***
(Prob > F)	0.0021	0.002	0.002	0.013	0.0049
DEMAND (summed lags)		0.268	0.238	0.081	0.087
(Prob > F)		0.545	0.697	0.86	0.85
Demand variable		z	Adjusted z	Residual z	Residual z
GDP growth (summed lags)		0.0597**	0.0575**	.0475*	0.0496**
(Prob > F)		0.023	0.033	0.063	0.05
Inflation (summed lags)		-0.0014	-0.0011	-0.0054	-0.004
(Prob > F)		0.948	0.522	0.803	0.851
TIER1					-0.0008
(p-value)					0.203
BIG					0.005
(p-value)					0.8
RISK					-0.0003
(p-value)					0.117
SUB					0.018
(p-value)					0.14
Observations	2135	2114	2114	1909	1909

1/ This table presents results from fixed effects panel regressions of regulated banks. The dependant variable is the growth rate of bank lending to the real sector. Four lags each are used of the first four variables in the table: the change in capital requirement, the demand proxy, GDP growth and inflation. The table entries show the sum of coefficients for these lags, together with the probability that the sum of coefficients is significantly different from zero. The remaining coefficients are shown together with p-values. *, ** and *** denote significance at the 10%, 5% and 1% level respectively. The same conventions are followed in the remainder of the tables presenting regression results.

Table 4b: The impact of minimum capital requirements and loan quality on bank lending 1/
Dependant variable: Rate of growth of lending

	1	2	3	4	5
Change in capital requirement ratio (summed lags)	-0.0677***	-0.062***	-0.0637***	-0.0695**	-0.0727***
(Prob > F)	0.0022	0.003	0.002	0.013	0.01
Change in write-offs (summed lags)	-0.0172	-0.0192	-0.0195	-0.036**	-0.0358**
(Prob > F)	0.264	0.179	0.198	0.026	0.028
DEMAND (summed lags)		0.289	0.292	0.125	0.135
(Prob > F)		0.504	0.63	0.77	0.757
Demand variable		z	Adjusted z	Residual z	Residual z
GDP growth (summed lags)		0.061**	0.059**	0.052**	0.0542**
(Prob > F)		0.021	0.029	0.043	0.035
Inflation (summed lags)		0	-0.011	-0.002	-0.001
(Prob > F)		0.999	0.543	0.904	0.96
TIER1					-0.0008
(p-value)					0.184
BIG					0.005
(p-value)					0.807
RISK					-0.0003*
(p-value)					0.1
SUB					0.017
(p-value)					0.164
Observations	2114	2114	2114	1909	1909

1/ This table is identical to Table 4 apart from the inclusion of four lags of the change in loan write-offs, where write-offs are measured in percent of risk weighted assets.

Table 4c: The impact of minimum capital requirements and loan quality on bank lending 1/
Dependant variable: Rate of growth of lending

	1	2	3	4	5
Change in capital requirement ratio (summed lags)	-0.0534***	-0.0488***	-0.0508***	-0.0593**	-0.0608**
(Prob > F)	0.006	0.007	0.005	0.019	0.015
Change in write-offs (summed leads)	0.0109	0.014	0.0129	-0.001	-0.001
(Prob > F)	0.6	0.477	0.0532	0.913	0.94
DEMAND (summed lags)		0.604	0.626	0.302	0.262
(Prob > F)		0.241	0.336	0.582	0.647
Demand variable		z	Adjusted z	Residual z	Residual z
GDP growth (summed lags)		0.053*	0.0471*	0.0417*	0.0436*
(Prob > F)		0.057	0.085	0.1	0.093
Inflation (summed lags)		0.012	-0.012	0.006	0.007
(Prob > F)		0.583	0.464	0.766	0.747
TIER1					-0.0001
(p-value)					0.705
BIG					0.0056
(p-value)					0.837
RISK					-0.0005
(p-value)					0.371
SUB					0.0204
(p-value)					0.246
Observations	1826	1812	1812	1635	1635

1/ This table is identical to Table 4 apart from the inclusion of four leads of the change in loan write-offs, where write-offs are measured in percent of risk weighted assets.

Table 5: The interaction of minimum capital requirements with capital buffers and bank size
Dependant variable: Rate of growth of lending

	1	2	3	4
Change in capital requirement ratio (summed lags)	-0.083**	-0.149***	-0.079**	-0.072**
(Prob > F)	0.018	0.006	0.027	0.020
DEMAND (summed lags)	0.087	0.033	0.078	0.073
(Prob > F)	0.85	0.94	0.86	0.88
Demand variable	Residual z	Residual z	Residual z	Residual z
GDP growth (summed lags)	0.0473*	0.0512**	0.0483*	0.0492*
(Prob > F)	0.065	0.041	0.055	0.055
Inflation (summed lags)	-0.005	-0.007	-0.005	-0.004
(Prob > F)	0.821	0.756	0.81	0.822
BUF in 1st quartile (interaction) (summed lags)	0.057			
(Prob > F)	0.287			
BUF less than median (interaction) (summed lags)		0.119**		
(Prob > F)		0.049		
SIZE in 4th quartile (interaction) (summed lags)			0.0316	
(Prob > F)			0.522	
SIZE greater than median (interaction) (summed lags)				0.0009
(Prob > F)				0.98
Observations	1909	1909	1909	1909

Table 6: Leakages from regulation of bank capital (Instrumental Variables)
Dependant variable: Rate of growth of lending of resident foreign branches

	Aggregate IV			Branch-specific IV		
	1	2	3	4	5	6
Change in lending by all regulated banks (summed lags)	-2.275***	-1.60*	-1.925*	-3.12***	-2.66***	-2.248**
(Prob > F)	0.009	0.065	0.1	0.001	0.003	0.049
DEMAND (summed lags)		0.321***	0.323***		0.292	0.087
(Prob > F)		0.002	0.006		0.186	0.74
Demand variable		Residual z	Residual z		Residual z	Residual z
GDP growth (summed lags)			0.0067			-0.21
(Prob > F)			0.901			0.14
Inflation (summed lags)			-0.0701*			-0.094
(Prob > F)			0.1			0.16
SIZE			-0.0101			-0.023
(p-value)			0.454			0.478
KAR			-0.0001			-0.0002
(p-value)			0.9			0.846
WHL			0.0011			-0.006
(p-value)			0.808			0.45
Hansen J statistic	38.04	31.54	11.1	2.6	4.677	2.15
(Prob > chi-squared)	0	0	0.03	0.63	0.32	0.71
Anderson-Rubin Wald test statistic	55.25	44.42	18.42	43.88	37.05	22.5
(Prob > chi-squared)	0	0	0.018	0	0	0.004
Stock-Wright S statistic	53.17	42.56	18.18	41.85	35.06	21.55
(Prob > chi-squared)	0	0	0.019	0	0	0.005
Observations	2645	2645	2645	2490	2490	2490
Instrument	Change in average capital requirement of all regulated banks			Change in capital requirement of regulated banks weighted by sectoral exposures of branch		

Appendix B: Panel VAR Estimation

In the main text we used the general specification:

$$\Delta \mathrm{l}_{i,t} = \alpha_i + \sum_{k=0}^{3} \beta_k \, \Delta \mathrm{KRR}_{i,t-k} + \sum_{k=0}^{3} \theta_k \, \mathrm{z}_{i,t-k} + X\Pi + e_{i,t} \qquad (1)$$

to investigate the effect of a cumulative change in capital requirements on quarterly real lending growth. Given the potential endogeneity problem, we controlled for bank-specific conditions that could govern both regulatory changes and lending decisions by introducing lags and leads of loan write-offs, and demonstrated the robustness of the estimates to these controls.

A recent study on fiscal policy by Romer and Romer (2010) constructs what the authors claim to be an exogenous measure of tax changes in the US. They then estimate the effect of tax changes on real GDP growth, under the assumption that their measure is indeed exogenous, with a single equation framework. They subsequently estimate a VAR treating real GDP growth and their measure of tax changes as endogenous variables. The estimated effects on real GDP growth from the VAR and the single equation approach are very similar. Furthermore, they find that an unexpected shock to output in their VAR does not affect their measure of tax changes. Based on these findings, they then conclude that "the tax shocks identified from narrative sources are indeed unrelated to past output movements". In this appendix, we follow a similar procedure andestimate a panel VAR to assess whether the results differ from those obtained with the single equation approach.

In particular, we estimate the following panel VAR model in reduced form:

$$\begin{pmatrix} \Delta \mathrm{KRR}_{i,t} \\ \Delta \mathrm{l}_{i,t} \end{pmatrix} = \sum_{j=1}^{3} \begin{pmatrix} \gamma_k & \gamma_{L+k} \\ \beta_k & \beta_{L+k} \end{pmatrix} \begin{pmatrix} \Delta \mathrm{KRR}_{i,t-k} \\ \Delta \mathrm{l}_{i,t-k} \end{pmatrix} + \begin{pmatrix} e_{i,t}^{\Delta \mathrm{KRR}_{i,t}} \\ e_{i,t}^{\Delta \mathrm{l}_{i,t}} \end{pmatrix} \begin{pmatrix} e_{i,t}^{\Delta \mathrm{KRR}_{i,t}} \\ e_{i,t}^{\Delta \mathrm{l}_{i,t}} \end{pmatrix} \sim N(0, \Sigma) \qquad (2)$$

where $\Delta \mathrm{KRR}_{i,t}$ and $\Delta \mathrm{l}_{i,t}$ enter in deviations from their unit-specific mean, which is equivalent to removing the bank specific fixed effect. $e_{i,t}^{\Delta \mathrm{KRR}_{i,t}}$and $e_{i,t}^{\Delta \mathrm{l}_{i,t}}$ are reduced-form error terms which are jointly normally distributed with a mean of zero and the variance-covariance matrix Σ. To understand the effect of a change in capital requirements, further assumptions need to be made. In Sims's (1980) seminal article he proposed the Choleski identification scheme, which consists of a lower triangular decomposition $B$of Σ, with zeros above the diagonal, to give the reduced form residuals a structural interpretation. A large literature in monetary economics has used this identification scheme, arguing that so long as slow moving variables, such as real GDP are ordered above fast moving variables such as interest rates, the shock to the interest rate equation can be interpreted as a monetary policy shock.[32] We adopt this convention here and order the change in

[32] See Christiano, Eichenbaum and Evans (1999) for more details.

capital requirements above real lending growth. In other words we assume that the change in capital requirements reacts to real lending growth with a lag:

$$\begin{pmatrix} e_{i,t}^{\Delta \mathrm{KRR}_{i,t}} \\ e_{i,t}^{\Delta \mathrm{l}_{i,t}} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \beta_0^{VAR} & 1 \end{pmatrix} \begin{pmatrix} \epsilon_{i,t}^{\Delta \mathrm{KRR}_{i,t}} \\ \epsilon_{i,t}^{\Delta \mathrm{l}_{i,t}} \end{pmatrix}$$

We argue that this is an economically justified assumption, as regulators typically only observe real lending growth with a lag. In addition, the procedures necessary to change an institution's capital requirement imply that regulators can only react with a delay, even if they are able to observe real lending growth contemporaneously. As a result, we can assign a structural interpretation to $\epsilon_{i,t}^{\Delta \mathrm{KRR}_{i,t}}$ and $\epsilon_{i,t}^{\Delta \mathrm{l}_{i,t}}$. In structural form, the VAR can be written as:

$$\begin{pmatrix} 1 & 0 \\ -\beta_0^{VAR} & 1 \end{pmatrix} \begin{pmatrix} \Delta \mathrm{KRR}_{i,t} \\ \Delta \mathrm{l}_{i,t} \end{pmatrix} = \sum_{j=1}^{3} \begin{pmatrix} 1 & 0 \\ -\beta_0^{VAR} & 1 \end{pmatrix} \begin{pmatrix} \gamma_k & \gamma_{L+k} \\ \beta_k & \beta_{L+k} \end{pmatrix} \begin{pmatrix} \Delta \mathrm{KRR}_{i,t-k} \\ \Delta \mathrm{l}_{i,t-k} \end{pmatrix} + \begin{pmatrix} \epsilon_{i,t}^{\Delta \mathrm{KRR}_{i,t}} \\ \epsilon_{i,t}^{\Delta \mathrm{l}_{i,t}} \end{pmatrix} \quad (3)$$

In general, impulse responses obtained from model (2) and the sum of coefficients from the model (1)will not be similar.[33] From a comparison of (1) and (3) however, it is easy to see that the cumulative sum of coefficients in model (1) and the cumulative impulse response to a capital requirement shock, $\epsilon_{i,t}^{\Delta \mathrm{KRR}_{i,t}}$, over the same horizon will be identical in population, if the following four requirements are jointly satisfied: i) $\Delta \mathrm{l}_{i,t}$ is not autoregressive, meaning that $\beta_{L+k} = 0 \; \forall \; k$; ii) $\Delta \mathrm{l}_{i,t}$ does not granger cause $\Delta \mathrm{KRR}_{i,t}$, meaning $\gamma_{L+k} = 0 \; \forall \; k$; iii) $\Delta \mathrm{KRR}_{i,t}$ is not autoregressive, meaning that $\gamma_k = 0 \; \forall \; k$; and iv) $\beta_0 = \beta_0^{VAR}$, meaning that the impact coefficient in model (1) is identical to the unbiased impact coefficient in the VAR.

Prior to exploring whether the data suggest that these conditions are met, it is useful first to discuss some methodological issues that arise in panel VAR estimation. One option is to pool the autoregressive coefficients across units, assuming identical autoregressive dynamics across all units.[34] If that assumption is violated, the resulting dynamic heterogeneity bias will typically lead to an upward bias in the VAR coefficients (Canova, 2007), meaning that it is easy to mistake a temporary effect of a shock for a permanent one. Alternatively, Pesaran and Smith (1995) propose the mean group estimator as a solution to the problem of heterogeneity in the lagged slope coefficients. This model is implemented by estimating the VAR model bank by bank and then averaging the bank-specific VAR estimates to obtain the panel estimate.[35] But, as demonstrated in Rebucci

[33] See Bagliano and Favero (1998) for an elaboration of this point in the context of monetary policy.
[34] See Goodhart and Hoffman (2008), Lzzetzki, Mendoza and Vegh (2010) or Towbin and Weber (2010) for an application of this approach.
[35] See Assenmacher-Wesche and Gerlach (2010) and Sa, Towbin and Wieladek (2011) for an application of this approach in the panel VAR context.

(2003), with small time series, as in our case, mean group panel VAR estimates may be subject to serious small sample bias. The nature of our application thus means that either estimator will be subject to econometric bias.

Recent work by Jarocinski (2010) proposes a solution to this difficult problem. He uses a Bayesian shrinkage approach to shrink every individual bank coefficient to a common mean:

$$a_{i,k} = \bar{a}_k \quad + \quad \mu_i \qquad \mu_i \sim N(0, \lambda \Delta_i)$$

Where $a_{i,k}$ is any of the individual VAR bank specific coefficients in model (2), $\bar{a}_k$ is the corresponding common mean and μ_i a stochastic error term, reflecting the difference between the particular coefficient for bank i and the common mean. The covariance matrix of ϵ_i is split into two parts, λ and Δ_i. Δ_i reflects the differences in magnitudes among VAR coefficients and needs to be set by the researcher.[36] λ on the other hand is treated as a parameter and inferred from the data. That is, the amount of shrinkage, and thus the degree of heterogeneity in the lagged slope coefficients, is determined by the data.

If λ=0, then the estimates of this model will be equal to pooled estimates. On the other hand, if $\lambda \to \infty$, then this approach will estimate completely separate bank specific VAR models. The flexibility of this method thus means that both the dynamic heterogeneity and small-sample bias will be minimised. We implement this model with Gibbs sampling as in Jarocinski (2010).[37] We sample 150,000 draws from the posterior, with 50,000 as burn in and retain every 100th draw to reduce auto-correlation among the draws. This leaves us with 1,000 draws from the posterior for inference. We plot the associated values of λ in Figure A1. One can clearly see that λ is fairly small, suggesting a pooled model. Furthermore the draws in Figure A1 are clearly uncorrelated, suggesting that each draw is an independent draw from the posterior, making these draws therefore suitable for inference.

[36] But in contrast to the approach in Jarocinski (2010), who sets Δ_i based on unit specific regressions, we set it based on pooled panel regressions, as the time horizon for some banks is not long enough to implement his approach.

[37] Other than the difference in setting Δ_i, we follow the approach in Jarocinski (2010) to the letter. Please see his paper for more details.

Figure A1

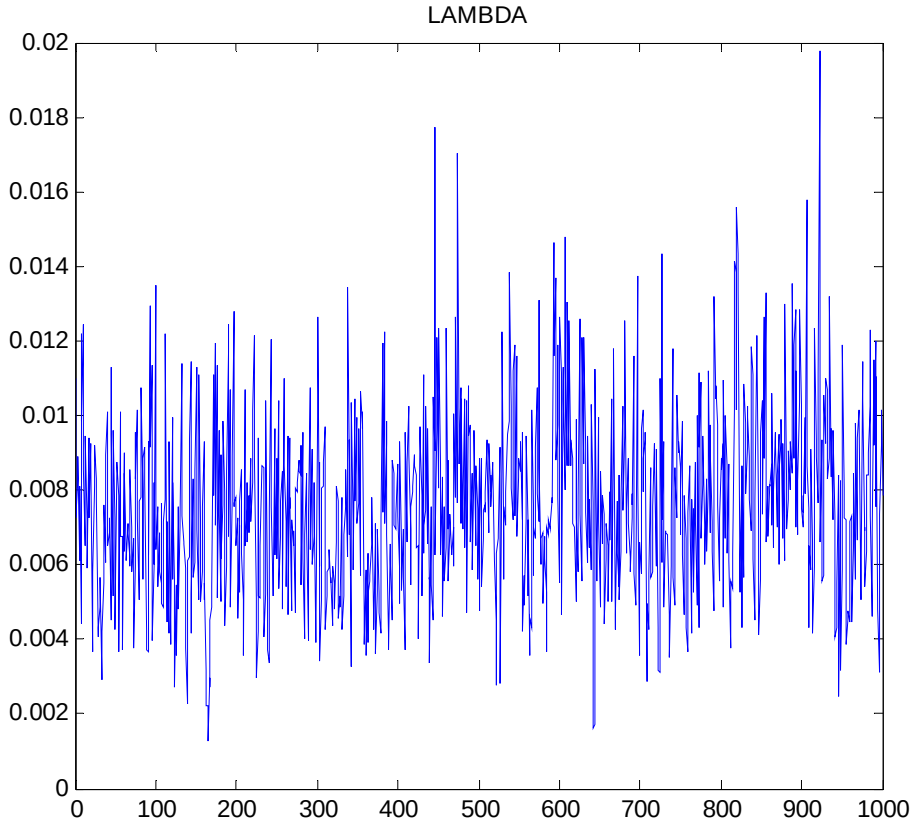


Figure A2 plots the impulse responses to a 100 basis points change in capital requirements shock and the associated 5th and 95thposterior coverage bands based on the 1,000 retained draws. The growth rate in real lending to the real economy falls by about 3.8% upon impact and declines back to zero fairly rapidly. In Figure A3, we assess the impact of a shock to real lending growth on the change in the capital requirement. The effect of a 100 basis point increase in lending growth is not significantly different from 0. To investigate the extent to which estimates from model (1) are biased, it is also instructive to investigate whether the four conditions under which results from both models would be identical hold in the population. In Figure A3, the response of real lending growth falls immediately back to 0 and the change in capital requirements is not statistically significantly different from 0. This suggests that conditions i) and ii) are satisfied. In Figure A2, the response of the change in capital requirement declines immediately back to 0 following impact. Furthermore, the impact response of real lending growth is -3.82, almost identical to the impact response estimated in model (1) of -3.5. Cumulating the real lending growth impulse response up to 3 quarters yields a median value of 4.64 - with a 5th and 95th percentile of -9.89 and -.0067,

respectively, which is a very similar value to the sum of coefficients in model (1) of between 6.4 to 7.16. These results suggest that all four conditions are satisfied.

In summary, the structural VAR model is less restrictive than model (1), both in the dynamics of the variables, as well as, *conditional* on the correct identification scheme, with respect to the exogeneity assumption regarding the changes in capital requirements variable. The similarity of the estimates from this approach to the single-equation approach suggest that, in fact the exclusion restrictions necessary for model (1) to provide an unbiased estimate, of the effect of the change in capital requirements on real lending growth, are not rejected by the data.

Figure A2

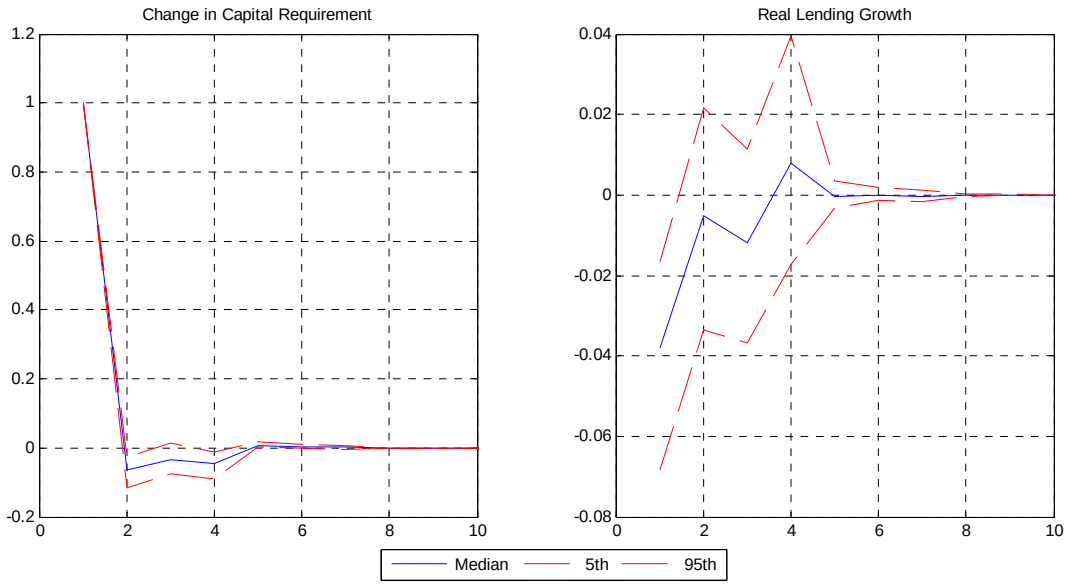
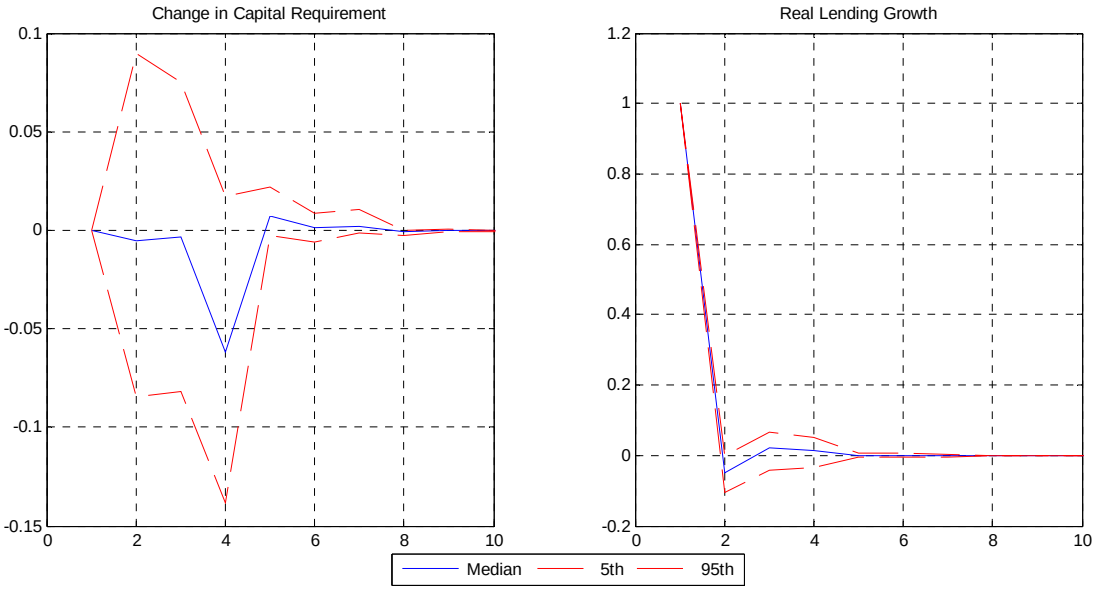


Figure A3


Change in Capital Requirement
0.1
0.05
0
-0.05
-0.1
-0.15
0
2
4
6
8
10
Real Lending Growth
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
2
4
6
8
10
Median
5th
95th