Does macro-pru leak? Evidence from a UK policy experiment

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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.

Key words: Macroprudential regulation, credit cycles, regulatory arbitrage, transmission mechanism, bank lending, instrumental variables.

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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. This cyclical variation is intended to cool off credit-fed booms, mitigate credit crunches, and boost capital and provisioning 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%). Importantly, the FSA based regulatory decisions on organization structures, systems and reporting procedures, rather than high-frequency financial analysis. This institutional characteristic allows us to treat changes in regulatory capital requirements as exogenous with respect to bank-specific credit supply, an assertion that we show has substantial empirical support. Although the FSA's prudential regime was explicitly *micro*-prudential in nature, our analysis of banks' credit supply responses to changes in minimum capital requirements holds important lessons for the efficacy of a future macro-prudential regime. This is especially the case because, as we shall see below, the FSA's bank-

[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.

specific changes in minimum capital requirements, when aggregated across the banking system in fact yielded a counter-cyclical regulatory impulse very similar to what is envisaged by 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 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]

[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. 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.

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 model) apply more to junior securities (like equity) than to relatively senior debt instruments. Equity may also be relatively costly as a source of finance because of ex post verification costs. For example, Diamond (1984) and Gale and Hellwig (1985) show that banks that offer debt contracts can economize on those costs.

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.[4] 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, 2012) 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

[4] 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.

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 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 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; 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 to isolate the bank-specific credit supply response to variation in regulatory minimum capital requirements. We are able to control for contemporaneous variation in loan demand by combining data on employment growth in different sectors of the economy with the sectoral composition of bank loan portfolios.[5] We document regulatory capital requirements at the level of individual banks, and we show that these requirements vary substantially cross-sectionally and over time. Furthermore, the institutional setup of

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[5] Our study differs in this respect from Francis and Osborne (2012), who also examine the relationship between minimum capital requirements and bank lending, but without an attempt to separate supply from demand. 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 minimum capital ratios.

the FSA regulatory process allows a causal interpretation of changes in the capital requirements on loan supply.

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 sufficiently 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.

Importantly, binding capital requirements should not be confused with banks always holding capital at the level of the minimum regulatory requirement. Rather, binding capital requirements simply mean that banks must adjust their behaviour when the regulatory minimum capital ratio changes. In general, binding capital requirements are perfectly compatible with a capital buffer chosen to minimize the costs of complying with capital requirements.[6] 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 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, 2012)). These studies find a substantial impact, and both conclude that capital requirements were binding on capital ratio choices. In Section 2, we confirm that minimum capital requirements

[6] See Repullo and Suarez (2009) and Aliaga-Diaz et al (2011) for two different frameworks modeling the dynamic behavior of capital buffers.

appear to have been binding on bank capital decisions continuously for our sample of UK banks from 1998 to 2007.

Necessary Condition 3: Limited Substitutability of Alternative Funding

The effectiveness of macro-prudential variation in regulatory capital ratios 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.[7] 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.[8] Thus, although "leakages" from all alternative sources of finance could potentially offset the variation in loan supply that results from macro-prudential 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.

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

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[7] There is a large empirical literature on the special characteristics of loans, beginning with James (1987).
[8] 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).

(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).[9] That means that if the FSA decided to raise minimum 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 words of Paul Tucker, Deputy Governor of Financial Stability at the Bank of England:

> 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 Sections IV and V, we investigate the extent to which these concerns about dilution are warranted. Specifically, we ask whether foreign branches operating 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 minimum capital ratio requirements and capital ratios. We also show that, despite the absence of any explicit macro-prudential mandate in FSA supervision, average minimum capital requirements across the banking system were in fact strikingly counter-cyclical.[10]

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[9] 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 IV, 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.

[10] 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).

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.

Sections 4 and 5 estimate 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 VI 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 minimum 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 public information. We collect quarterly data on minimum 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.[11]

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

[11] 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.

each bank that would trigger regulatory intervention if breached.[12] 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....
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> 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 gaps in the early Basel I system, which did not consider risks related to variation in interest rates, or legal, reputational and operational risks.[13] Our empirical analysis below confirms that view; changes in 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 loan write offs). Rather, cross-sectional differences in minimum 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.

During this time period, the FSA's approach to supervision was implemented via ARROW (Advanced Risk Responsive Operating frameWork). While in theory,

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[12] 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.

[13] Some institutions were reviewed on a continuous basis, while others were reviewed only every 18-36 months. Conceptually, this means that the former could have experienced a number of subsequent small increases, with the latter experiencing larger changes on a more infrequent basis. However, as figure 3 suggests, the number of banks with more than 3 changes in a 10-year period is small. Furthermore, as shown by the panel VAR analysis in appendix B, the persistence of changes in the capital requirement is close to 0. This suggests that regulatory changes were infrequent events.

the ARROW approach encompassed prudential risks, this was not one of the core supervision areas, and in practice most of the focus was on systems and processes rather than business risks and sustainability. Indeed, in his high-level review of UK financial regulation following the global financial crisis, Lord Turner, the chairman of the FSA, concluded that ‘Risk Mitigation Programs set out after ARROW reviews therefore tended to focus more on organisation structures, systems and reporting procedures, than on overall risks in business models’ (Turner, 2009). Furthermore, an inquiry into the failure of the British bank Northern Rock notes that ‘Under ARROW I[14] there was no requirement on supervisory teams to include any developed financial analysis in the material provided to ARROW Panels’, where developed financial analysis is defined as information on the institution’s asset growth relative to its peers, profit growth, the cost to income ratio, the net interest margin and reliance on wholesale funding and securitisation (FSA, 2008a). Thus high-frequency changes in bank’s balance sheet characteristics did not appear to be instrumental in determining minimum capital requirements during the sample period. As a result of this institutional setup, it is unlikely that bank-specific lending growth was a determinant of FSA regulatory decisions.[15]

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 trigger ratio is less than or equal to the trigger ratio on the banking book. When we describe capital requirements in tables and graphs, the banking-book trigger ratio, which is also the measure used in our regression analysis, will often be referred to as “trigger ratio” and “capital requirement ratio”. There are two main reasons for our focus on the banking book trigger ratio. First, it allows comparability between banks that maintain trading books and those that do not. Second, and more important, it avoids recording spurious regulatory changes when a bank’s banking book and trading book expand at different rates. To understand this

[14] The FSA published revised ARROW guidelines in 2006, called Arrow II (FSA, 2006). However, financial institutions did not have to submit ‘developed financial analysis’ as part of the ARROW II either (See page 28 of FSA, 2008b)
[15] This assertion receives further support from the panel-VAR analysis described in section III.

point, consider a bank with a different banking book trigger ratio and trading book trigger ratio, for which, in a given quarter, the FSA makes *no* regulatory change, i.e. both the banking book trigger ratio and the trading book trigger ratio remain exactly the same as in the previous period. Assume that in this quarter the bank's banking book grows slightly relative to its trading book. Focusing on the combined trigger ratio produces the misleading datum of a change in regulatory minimum capital ratios, even though the FSA has not taken any such action. By focusing on the banking-book trigger ratio to measure regulatory changes, our measure captures actual FSA-mandated changes to the trigger ratio, avoiding distortions that result from changes in the proportion of risk-weighted assets held in the trading book.

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. Few banks experience more than 5 events which, given the 9 year period, means that regulatory action is typically infrequent.

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

[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.

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 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.[19]

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[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).

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

[19] The fact 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 introduction of interest rate risk measurement in 1998 and 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.

To better understand the FSA's approach to setting capital requirements, 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 exposure divided by the bank's total lending. 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.

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. This is consistent with the institutional setup documented earlier, in which FSA regulatory decisions were not typically based on high-frequency changes in balance sheet variables.

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 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, 2012) 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 to the non-financial corporate sector. We deliberately exclude lending within the financial sector and lending to households. Lending within the financial sector is excluded because our aim is to examine the credit supply impact of capital requirement changes on the real economy. Within the financial sector, gross assets and liabilities are typically much larger than net flows; an expansion or contraction in a bank's gross claims on the financial sector is therefore only tenuously related to credit supply to the real economy. This would not matter if claims on the financial sector were small relative to lending to the real economy, but in the UK this is not the case, and we do not want our data to reflect primarily high frequency movements in financial claims. Lending to households is excluded for two reasons. First, UK household sector lending is dominated by a handful of UK-owned banks (Aiyar (2011) documents that over 99% of lending to this sector is undertaken by 15 banks). Second, mortgage lending comprises the majority of household lending, and during the sample period studied here, mortgage lending was often transferred off-balance sheet from banks to special purpose vehicles (SPVs).[20]

Hence our measure of bank lending consists of all of the sectoral loan categories of a bank's lending except for its loans to financial institutions and households. As discussed in Section I, 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 introduce a new way of controlling for bank loan demand, by exploiting information on each bank's exposure to different economic sectors.

Our dataset provides us with information on lending by bank i to 14 different sectors. We collected data on employment levels for each of these different sectors at each point in time. Our bank-specific measure of demand is therefore $z_{it} = \sum_q s_{iqt}\Delta z_{qt}$, where s_{iqt} denotes the share of sector q in bank i's lending portfolio in period t. Δz_{qt} is the growth rate of real activity in sector q, which we define as the quarter t on t-6 quarter employment growth rate, expressed at quarterly frequency[22].

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[20] The Bank of England reporting form used in this study to disaggregate lending by sector—the AL form—only includes securitized lending from January 2010 onwards.

[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.

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

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 minimum 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..

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 4 reports six 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. The first column does not include any controls. The second column introduces the demand variable as a control, with the third column introducing standard macroeconomic variables used as controls in other studies, GDP growth and inflation.[23] The fourth column introduces bank-specific characteristics as additional controls. Specifically, we include TIER1, RISK, SUB, and BIG. TIER1 is Francis and Obsborne's (2009, 2012) measure of a bank's low cost of equity capital relative to other banks (which is revealed by its ratio of tier 1 to total regulatory capital). RISK is a measure of the riskiness of bank assets: the

[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, by 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 (2012)). 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.

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. Finally, the fifth and sixth columns add the contemporaneous value and three leads or lags of changes in the write-offs to risk-weighted asset ratio to control for possible omitted variable bias due to changes in loan quality.

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 0.057 and 0.08.That is, an increase in the capital requirement ratio of 100 basis points induces, on average, a cumulative fall in lending growth of between 5.7 and 8 percentage points.[24] The demand variable is statistically significant in all but one specification with a value of about 0.02 to 0.028, which means that for a one percent increase in sectoral employment (weighted by the bank *i*'s portfolio shares), lending growth by bank *i* rises by between 2 to 2.8 percent. The fact that the bank-specific demand controls are significant in *addition* to the GDP growth term suggests that demand conditions evolve in a heterogenous way across sectors. Bank-specific balance sheet characteristics used as controls in other studies (TIER1, RISK, SUB, and BIG) are generally not highly statistically significant, with the exception of SUB in one of the specifications.[25]

In principle, specification 4 could be subject to endogeneity problems, as a result of both reverse causality and omitted variable bias. We showed in Section 2 that the FSA's institutional setup makes reverse-causality between lending growth and the change in capital requirement unlikely. At the same time we do not want to rule out this possibility ex ante.

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

[25] The positive coefficient on SUB in the last column of Table 4 indicates that, ceteris paribus, the loan supply growth of foreign subsidiaries is higher than that of domestic banks. We can think of two explanations for this result. It may simply reflect the smaller average size of foreign subsidiaries. Alternatively, the positive coefficient could reflect the fact that our sample period is one of high average loan opportunities in the UK. Foreign subsidiaries are able to shift capital from other operations to their UK operations during this high-growth period. In contrast, domestic banks operating solely in the UK (the most common profile of a domestic bank in our sample) would have had to raise capital in the market to expand their operations, which presumably would have been more costly. Whichever is the case, there is no significant difference between foreign subsidiaries and UK-owned bank in the slope co-efficient on the change in minimum capital requirements (unreported above).

To assess the extent to which endogeneity bias from reverse causality may be a problem, Aiyar, Calomiris and Wieladek (2013a) estimate a panel VAR in two variables: lending growth and changes in minimum capital requirements. 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 due to reverse causality, conditional on a valid VAR identification scheme, and some other conditions (which we find to be satisfied in our data), the VAR and single-equation results should be similar.[26] Aiyar, Calomiris and Wieladek (2013a) find that the VAR impact coefficient of a change in the minimum capital requirement on lending growth is 3.8%, almost identical to our single equation estimates of between 3.76% and 3.94% (depending on which of the specifications in Table 4 is chosen). Furthermore, they also show that the cumulative lending growth impulse response is also similar to the cumulative response estimates reported in Table 4. The comparison therefore strengthens the case that the single equation estimate of the impact of the regulatory change on lending growth is unbiased.

Even absent reverse causality, 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.[27] 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 we investigate this in columns 5 and 6 of Table 4. Column 5 replicates the specification in column 4 but

[26] For more details on this approach, see Aiyar, Calomiris and Wieladek (2013a)

[27] Bank-specific data on non-performing loans, a more direct measure of the quality of the loan portfolio, are not available. However, data on write-offs are available from FSA data and from responses to the Bank of England's PL form (http://www.bankofengland.co.uk/statistics/Documents/reporters/defs/form_PL.pdf).

with contemporaneous and lagged values of changes in the write-off to risk-weighted asset ratio 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 the coefficients on the regulatory changes become insignificant, or diminish in magnitude. This does not appear to be the case, as the sum of the contemporaneous and lagged write-off coefficients are not statistically significant determinants of lending growth and the sum of coefficients on the changes in capital requirements is unchanged.[28]

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). The last column of Table 4 replicates column 4, but with contemporaneous and *leading* values of changes in the write-off to risk-weighted asset ratio (rather than lags) introduced as additional explanatory variables. In this specification, leads of write-offs have a statistically significant positive effect on lending growth and the coefficient on changes in capital requirement declines slightly in the presence of leads of write offs. This positive coefficient does not suggest that regulators raised capital requirements in anticipation of higher future write offs (in that case the observed sign on lead write-offs would be negative). Our results seem more consistent with the FSA's stated intent impose use higher minimum capital requirements in response to interest rate risk or operational risk, not higher loan default risk.[29]

As a further robustness check, we estimated, but do not report, the specifications in Table 4 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

[28] Note that in the NBER working paper version of this paper, we reported a statistically significant effect of lagged changes in the write-off to asset ratio. The significance of lags of write-offs in that version of the paper, as opposed to leads of write-offs in this version, reflects a change in the definition of the demand control variable used in the specifications. Our prior demand specification used sectoral lending of other banks to define the demand control, but this is subject to criticisms related to potential cross-sectional inter-dependence of lending..

[29] The positive coefficient on leads of write offs could reflect a positive correlation between a greater willingness to lend (which is associated with higher loan supply growth) and a deterioration in loan quality.

techniques, the instrumentation schemes tend to be very data intensive, and we believe are not appropriate for the sample studied here.[30] 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.

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

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. We find some evidence (column 2) that the response of a bank with a capital buffer below the median—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 with a capital buffer above the median. This effect is not statistically significant for banks with a capital buffer in the lowest quartile (column 1), although the sign indicates, similarly, a lower responsiveness.

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

[30] 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.

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.[31]

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-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

[31] 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)).

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 a branch-specific reference group weighted by the sectoral exposures of the branch. z_{it} is the loan demand proxy, as defined previously.

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}.

Let $\tilde{z}_{qt}$ denote the log of aggregate lending by all regulated banks to sector q in period t. Lending growth by the *branch-specific reference group* is constructed as: $\Delta l_{jt}^{REF} = \sum_q s_{jqt-1} \Delta \tilde{z}_{qt}$, where, as before, s_{jqt} denotes the share of sector *q* in bank *j*'s lending portfolio in period *t*.

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 change in reference group capital requirements, ΔKRR_{jt}^{REF} is defined as: $\Delta KRR_{jt}^{REF} = \sum_q s_{jqt-1} \Delta KRR_{qt}$. Note that if a sector experiences no change in its capital requirement (i.e. all the banks that lend into this sector experience no change in capital requirements), then by construction this sector has zero weight in the expression ΔKRR_{jt}^{REF}.

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. Column 1 does not include any controls, while column 2 adds our definition of demand. In Table 4, we found that the leads of changes in the write-off to asset ratio is significant for explaining lending growth and may affect the coefficient on changes in capital requirements. Column 3 thus introduces a branch-specific reference group changes in the write-off to asset ratio (defined analogously to the reference group for the change in capital requirements). Columns 4 to 6 introduce, in addition, GDP growth and inflation.

Could lending growth in the UK by foreign branches be affected not just through FSA action on regulated banks, but also by regulatory changes in the foreign branch's home country? Clearly this is possible, but notes that in order for this to bias our estimate of leakages, it must be the case that home country regulation on branch *j* is correlated with FSA regulation on the UK reference group of branch *j*. We have no a priori reason to believe that this is the case. Nonetheless, in columns 5 and 6 we experiment with introducing home country effects. Column 5 introduces the minimum capital requirement ratio in the home country; Capital, a measure of the stringency of other types of capital regulation in the home country; and Official, the power of the authorities to affect bank activity in their home country.[32] Column 6 adds home country fixed effects, which are not reported. Column 6 also adds GDP growth and inflation in the home country as additional regressors, to pick up any impact from changes in demand in the home country (although our prior is that the inclusion of exclusion of these variables should make little difference to the co-efficient of interest, since there is no obvious reason to expect UK regulatory requirements to be correlated with home country demand conditions).

We find that lending by foreign branches is strongly negatively related to instrumented lending by the foreign branch's reference group.[33] 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.[34] This conclusion is robust to the inclusion of home country fixed effects, indices of home country regulation, and home country macroeconomic conditions. Table 6 also reports a set of

[32] Data on these variables are taken from the World Bank's survey on 'Bank Regulation and Financial Supervision' (see Barth, Caprio and Levine, 2008). The survey has been carried out in 1999, 2003 and 2007, which means that we only have three time-series observations on regulatory changes. Our assumption in translating these to quarterly frequency is that regulation remains unchanged until the next survey is released. As a result these variables take the same value from 1998Q3 to 2002Q4, from 2003Q1 to 2006Q4 and from 2007Q1 onwards. See Barth, Caprio and Levine (2008) for an exact definition of these variables. Results given here are for specifications in which the home country variables are introduced in levels. Changing the specifications to include these variables in differences does not alter the results qualitatively.

[33] The leakages considered in this section pertain to credit substitution of regulated banks by foreign branches. In unreported preliminary regressions, we tested to see whether regulated banks respond to *each other's* changes in capital requirements. We found no significant response. Our interpretation of this fact is as follows: UK capital requirements on average are much higher than those of other countries (which apply to those countries' branches in the UK). The average for UK banks and subsidiaries is 11%, compared to other countries at 8% (the minimum in the UK). Thus, foreign branches have a comparative advantage in being the ones to respond to changes in a UK bank's capital requirements.

[34] The negative coefficient on inflation may reflect a response of foreign branches related to real exchange rate considerations.

post-estimation statistics. Across all specifications, the Sargan-Hansen test of overidentifying restrictions cannot reject the validity of the instruments. 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 not been tabulated.[35] However, to assuage concerns about weak instruments, we report two tests for robust inference in the presence of weak instruments.[36]

What do these numbers say about the magnitude of leakages from prudential regulation? The simple average of the estimated coefficients in Table 6 is 3.0. 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 3.0% 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 billion, about 15 times larger than quarterly lending by the average foreign branch, which stood at £630 million. 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: 32.9% = (3.0*(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.[37] 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

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

[36] 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.

[37] 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. The reduced form regressions also weakly support (at the 10% level of significance) asymmetric leakages; that is, the leakage is stronger in response to increases than decreases in minimum capital requirements on regulated banks (See Aiyar, Calomiris and Wieladek (2013b) for a detailed exploration of this issue). However, this asymmetrical response is not found in the response of regulated bank lending to increases / decreases in minimum capital requirements.

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.[38] This evidence validates the focus on reciprocal arrangements between financial regulators to prevent leakages from forthcoming 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

[38] It should be mentioned that the analysis of leakages here can be extended along several dimensions, and we are undertaking several such extensions. For example in a forthcoming paper (Aiyar, Calomiris and Wieladek (2013b)), we specifically examine banking conglomerates: groups that operate in the UK both as a subsidiary and a branch. Preliminary analysis suggests that these groups shift loans between the balance sheet of the (regulated) subsidiary to the (unregulated) branch in response to changes in the former's trigger ratio, and that the magnitude of this effect is greater than leakages that occur between subsidiaries and branches unrelated to each other.

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).[39] 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. Differences from macroeconomic studies may also arise because our paper studies a bank's credit supply response to changes in its *own* minimum capital requirements rather than a system-wide change in such requirements. It is possible that a bank's loan supply response to such a change, which gives it a cost advantage or disadvantage relative to competing regulated banks, is larger than its response to such a change under a regime under which all competing regulated banks also face a similar change, leaving the relative cost advantage of the bank unaltered. In this case, a similar system-wide change in the minimum capital requirement of all banks would have a smaller aggregate credit supply impact than implied by the co-efficient estimates in the first part of this paper. However, this point should not be overstated, because we also present evidence that in fact such micro-prudential regulatory changes, when aggregated, were counter-cyclical in nature. Minimum capital ratio changes among banks tended to be synchronized, which would tend to reduce or eliminate the relative cost advantage experienced by a bank facing a regulatory change under the micro-prudential regime.

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

[39] 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-thirds of that. These large magnitudes are consistent with another observation noted in our study: that banks do not appear to respond to changes in minimum capital requirements by raising nominal capital, instead carrying out the full amount of adjustment through changes in assets.

other countries. The effect of capital requirements on aggregate lending may become stronger once the reciprocity agreement embedded in Basel III is enforced and the branch leakage documented in this paper eliminated. Moreover, 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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Appendix A: Charts and Tables

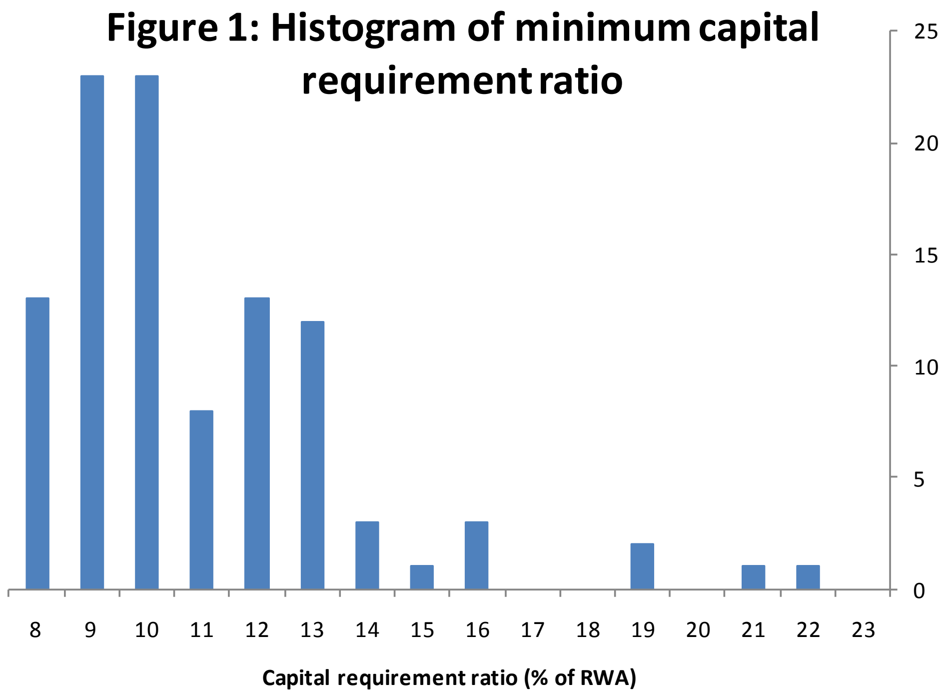
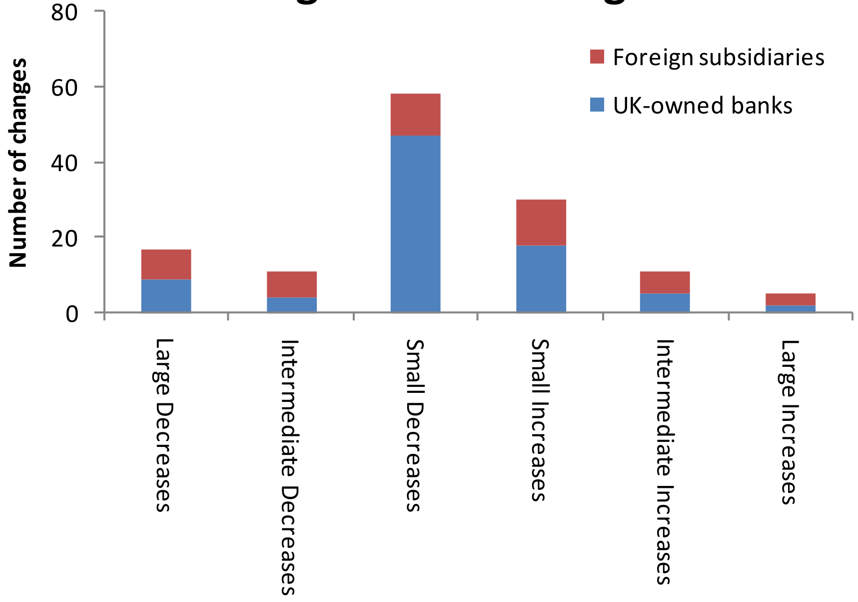


Figure 2: Distribution of changes in capital requirement ratios by magnitude of change



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

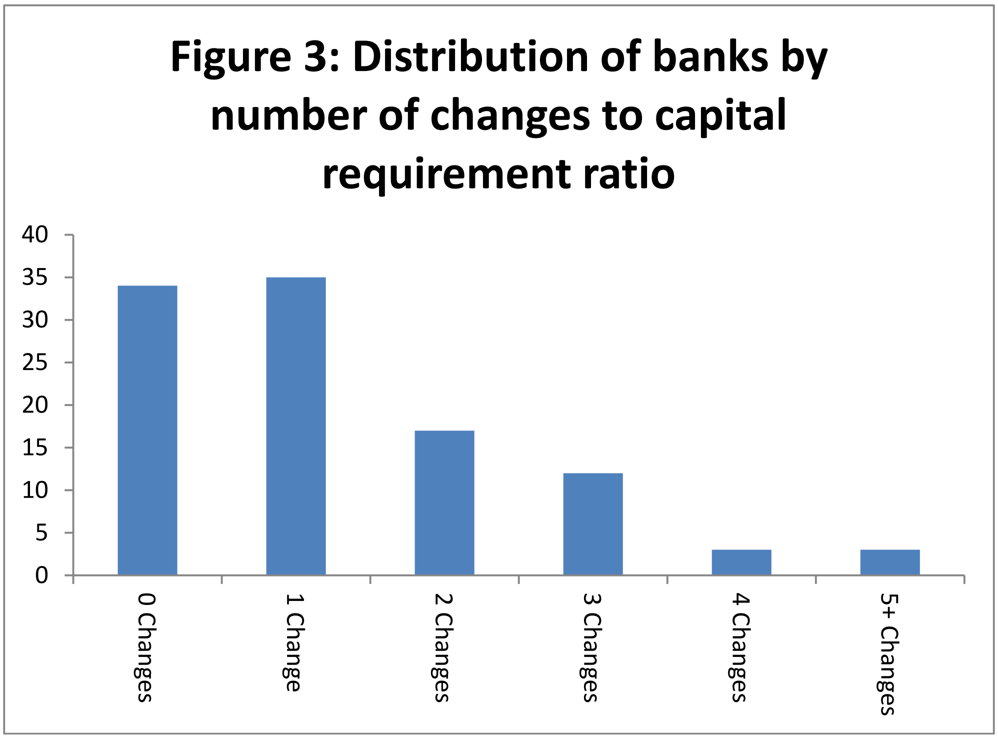


Figure 3: Distribution of banks by number of changes to capital requirement ratio
40
35
30
25
20
15
10
5
0
0 Changes
1 Change
2 Changes
3 Changes
4 Changes
5+ Changes

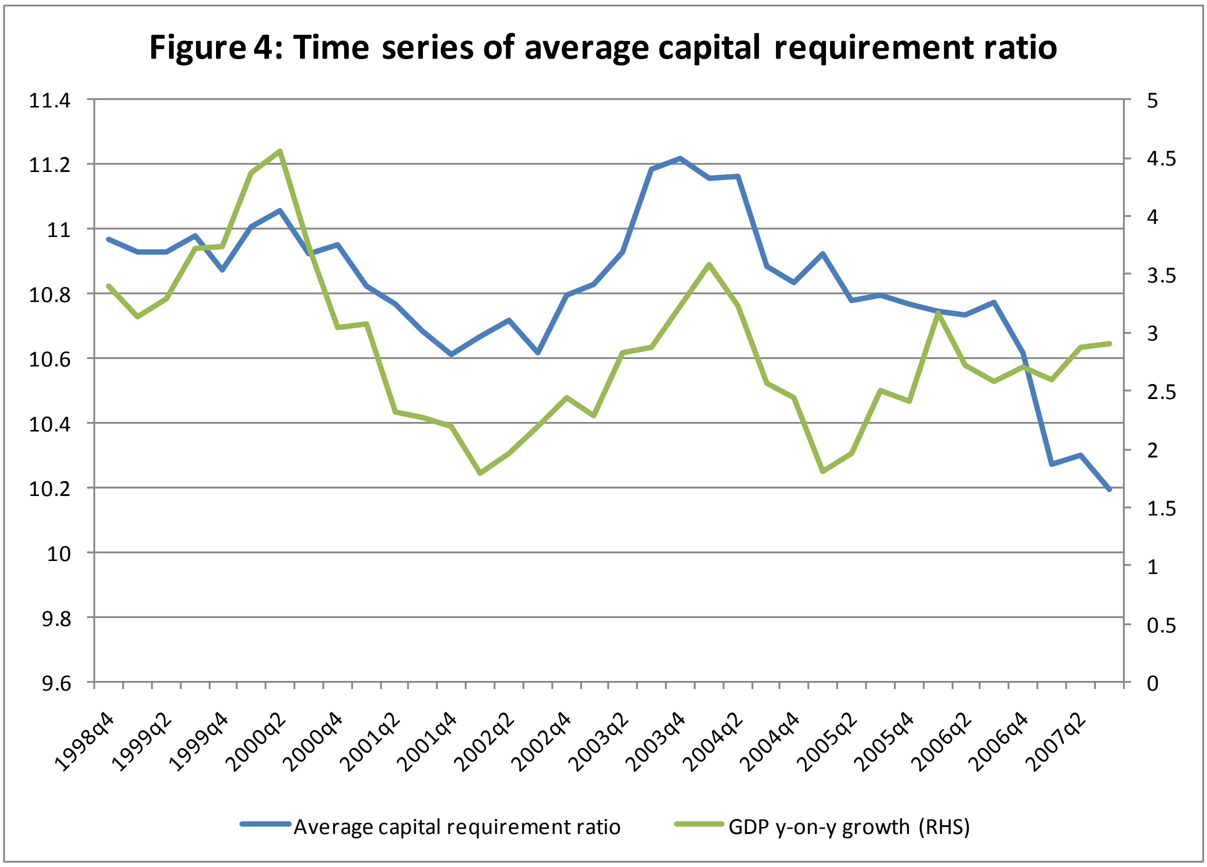


Figure 4: Time series of average capital requirement ratio
11.4
11.2
11
10.8
10.6
10.4
10.2
10
9.8
9.6
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1998q4
1999q2
1999q4
2000q2
2000q4
2001q2
2001q4
2002q2
2002q4
2003q2
2003q4
2004q2
2004q4
2005q2
2005q4
2006q2
2006q4
2007q2
Average capital requirement ratio
GDP y-on-y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

Figure 5: Time series of average weighted capital requirement ratio

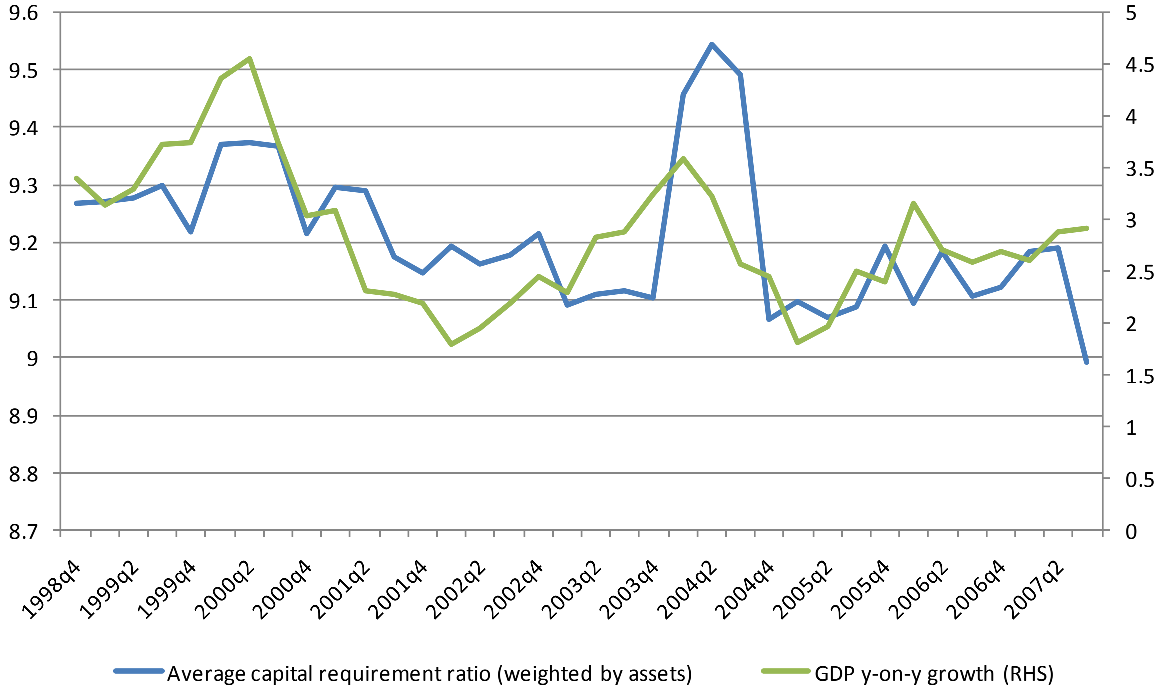


Figure 6: Time series of average weighted capital requirement ratio (cumulated changes)

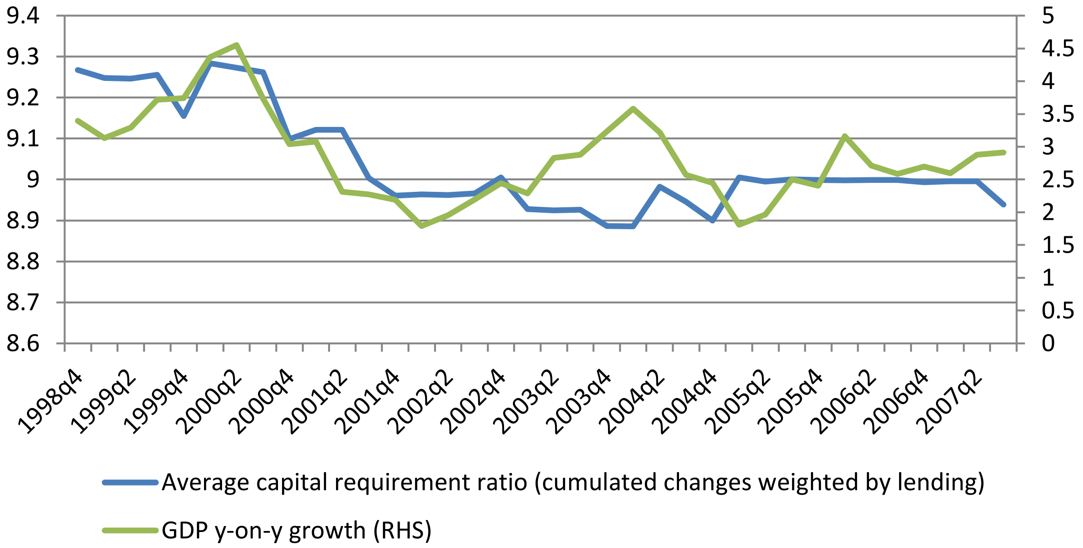


Figure 7: Co-variation between average capital requirements and average capital

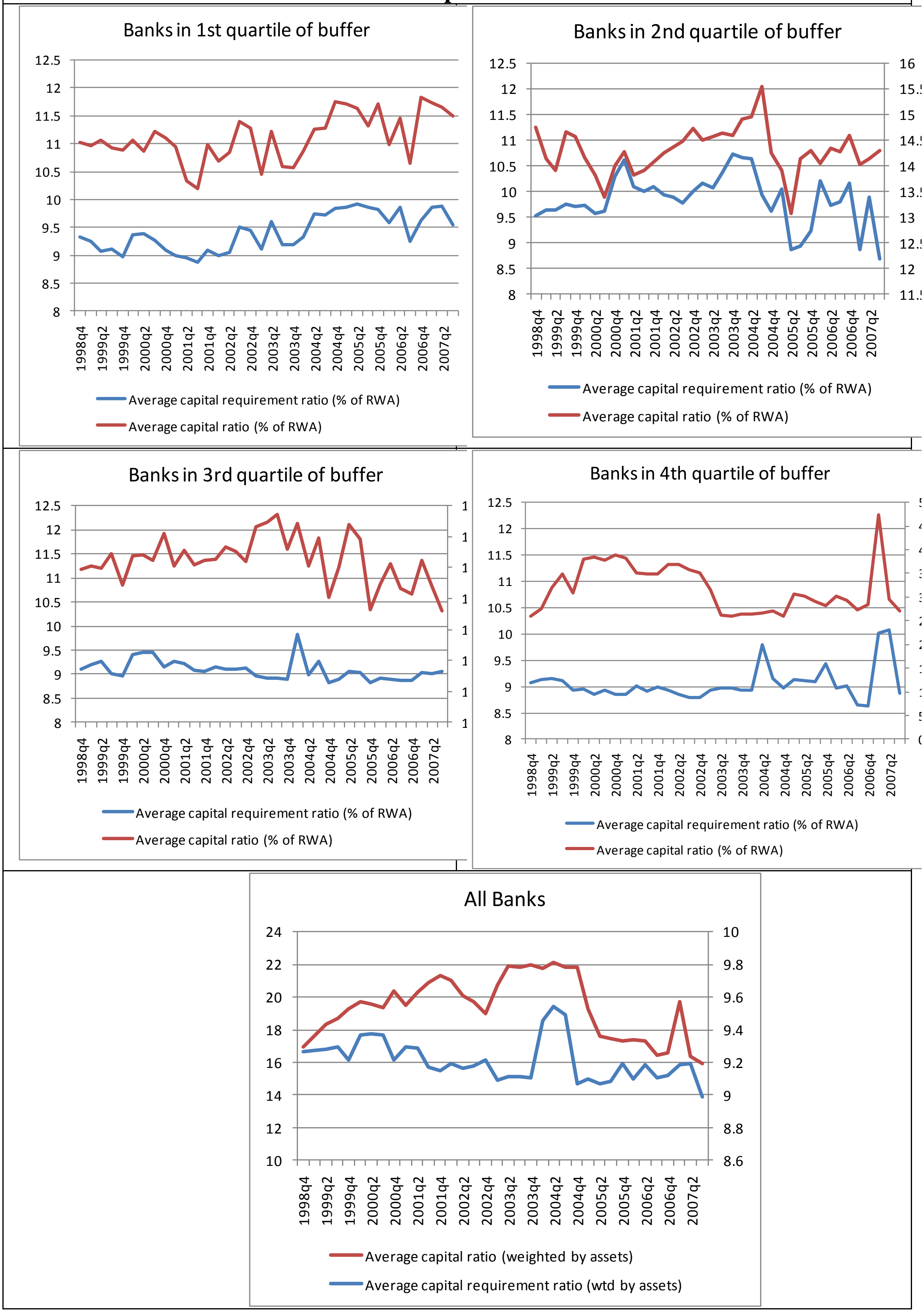


Figure 8: Sectoral pattern of lending by foreign branches

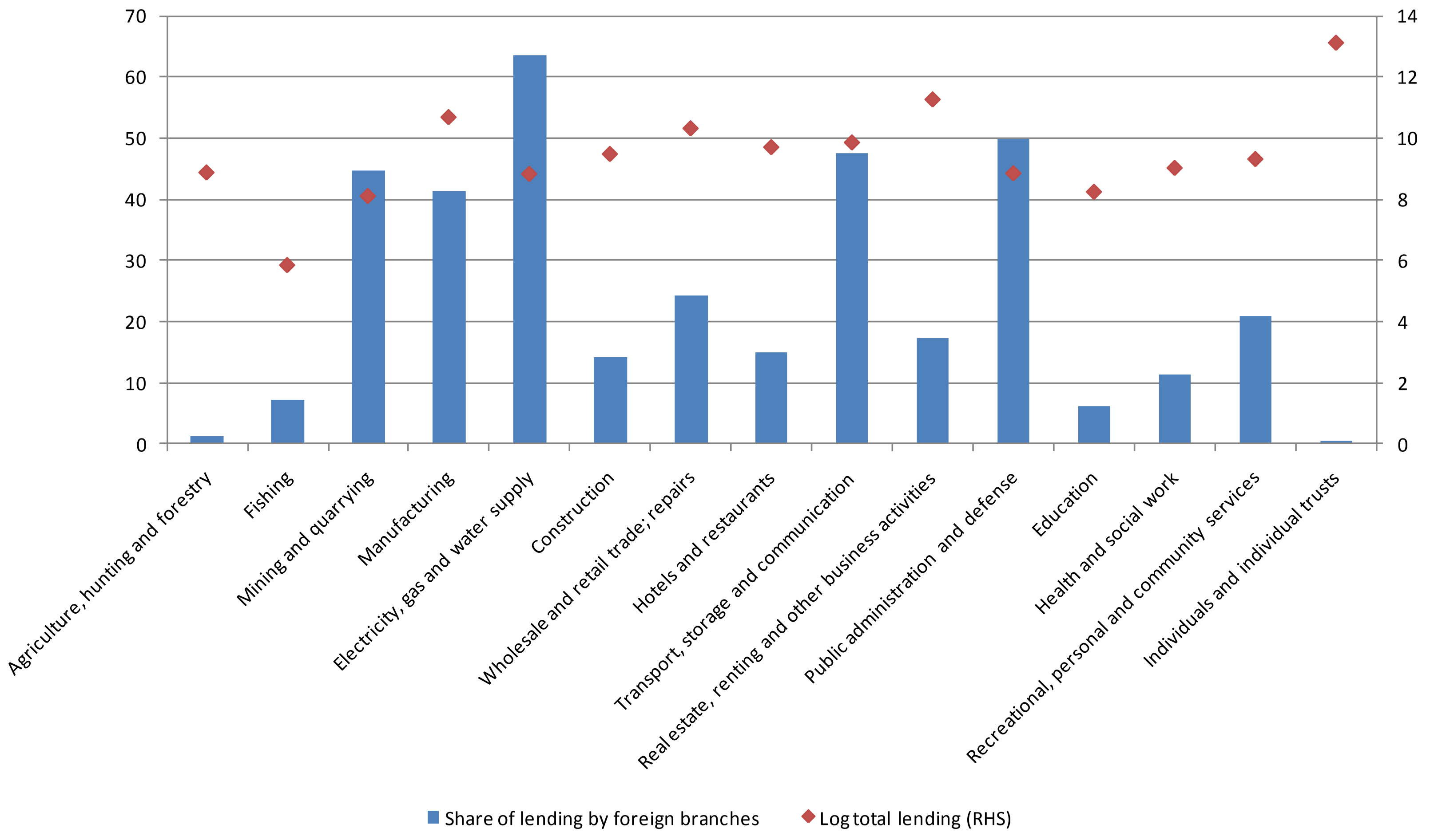


Table 1: Variables and data sources

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	25 pc	75 pc	Obs
Minimum capital requirement ratio	Regulated banks	%	10.8	2.26	8	23	9	12	2,630
Change in min capital requirement ratio	Regulated banks	Basis points	-1.4	29.7	-500	500	0	0	2,524
Lending to real economy	Regulated banks	£ 000s	9,483	28,510	0	274,140	121	3,600	2,630
Lending to real economy	Foreign branches	£ 000s	630	893	0	10,175	82	816	3,976
Change in lending to real economy	Regulated banks	%	0.7	16.1	-98.3	85.3	-2.6	5.3	2,479
Change in lending to real economy	Foreign branches	%	0.4	20.6	-98.7	98.4	-9.3	8.3	3,738

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 4: The effect of changes in bank minimum capital requirements on regulated bank lending growth

Dependent variable: Real regulated bank lending growth	1	2	3	4	5	6
DBBKR	-0.073**	-0.08***	-0.078***	-0.076***	-0.075***	-0.057***
(Prob>F)	0.0121	0.00554	0.00148	0.00114	0.00125	0.00174
Demand		0.02**	0.025**	0.028**	0.028**	0.023
(Prob>F)		0.0461	0.0433	0.0237	0.0261	0.134
GDP growth			0.057*	0.061*	0.061*	0.053
(Prob>F)			0.0860	0.0640	0.0642	0.140
Inflation			0.00872	0.00674	0.00659	-0.00197
(Prob>F)			0.669	0.741	0.746	0.932
Lags of Writeoffs					-0.00593	
(Prob>F)					0.586	
Leads of Writeoffs						0.0269**
(Prob>F)						0.0381
TIER1				0.000605	0.000615	0.000654
				(0.000592)	(0.000591)	(0.000613)
BIG				0.0230	0.0232	0.0124
				(0.0182)	(0.0182)	(0.0250)
RISK				0.00106	0.00107	0.00143*
				(0.000794)	(0.000791)	(0.000742)
SUB				0.0219	0.0219	0.0451***
				(0.0173)	(0.0173)	(0.0125)
Constant	0.00991	0.00488	-0.0415	-0.150**	-0.148**	-0.157**
	(0.00702)	(0.00851)	(0.0365)	(0.0724)	(0.0721)	(0.0652)
Observations	1,815	1,815	1,815	1,814	1,814	1,564
Number of banks	82	82	82	82	82	72

This table presents results from panel regressions of regulated banks. The dependent variable is the growth rate of bank lending to the real sector. We use the contemporaneous and 3 lags of each of the first 5 variables: the change in the banking book capital requirement, the demand proxy, real GDP growth, Inflation and the lags of the change in the writeoff to total asset ratio. For the 6th variable, we use the contemporaneous value and 3 leads of that variable instead. We report the sum of coefficients and F-statistics in parenthesis for these variables. For the remaining variables we report the estimated coefficients and standard errors in parenthesis. For statistical significance, we use the following convention throughout: *** p<0.01, ** p<0.05, * p<0.1

Table 5: The interaction of bank minimum capital requirements with the capital buffer and bank size

Dependent variable: Real regulated bank lending growth	(1)	(2)	(3)	(4)
DBBKR	-0.079***	-0.12***	-0.091***	-0.079***
(Prob>F)	0.006	0.0006	0.001	0.008
GDP growth	0.057*	0.06*	0.057*	0.058*
(Prob>F)	0.085	0.07	0.083	0.08
Inflation	0.00961	0.00968	0.00900	0.00917
(Prob>F)	0.64	0.64	0.66	0.66
Demand	0.025**	0.026**	0.026**	0.025**
(Prob>F)	0.047	0.042	0.04	0.046
Buffer in first quartile interaction	0.016			
(Prob>F)	0.76			
Buffer less than median interaction		0.044*		
(Prob>F)		0.06		
Size in fourth quartile interaction			0.068	
(Prob>F)			0.19	
Size above median interaction				0.001
(Prob>F)				0.002
Constant	-0.0427	-0.0446	-0.0418	-0.0448
	(0.0370)	(0.0369)	(0.0362)	(0.0833)
Observations	1,815	1,815	1,815	1,815
Number of banks	82	82	82	82

This table presents results from panel regressions of regulated banks. The dependent variable is the real growth rate of bank lending to the real sector. Variables in common with table 4 are described in the footnotes to that table. The additional variables in this table are interactions of the change in capital requirements with time-invariant indicators on the buffer and SIZE. For statistical significance, we use the following convention throughout: *** p<0.01, ** p<0.05, * p<0.1

Table 6: Leakages from bank minimum capital requirements

Dependent variable: Real branch lending growth	(1)	(2)	(3)	(4)	(5)	(6)
Regulated bank lending growth	-3.18***	-2.83***	-3.14**	-2.88**	-2.74**	-3.27**
(Prob>F)	0.00109	0.00116	0.0142	0.0222	0.0276	0.0329
Demand		0.082**	0.09**	0.056	0.066	0.061
(Prob>F)		0.0287	0.0437	0.154	0.102	0.17
Leads of changes in Writeoffs			0.621	0.664	0.71*	0.701
(Prob>F)			0.167	0.127	0.0949	0.132
GDP growth				-0.20*	-0.19*	-0.24*
(Prob>F)				0.0593	0.0624	0.0567
Inflation				-0.13***	-0.14***	-0.14**
(Prob>F)				0.00840	0.00588	0.0168
Home Country KR					-1.550	-2.017
					(3.628)	(4.147)
CAPITAL					-0.156*	-0.186
					(0.0940)	(0.113)
OFFICIAL					0.137*	0.126
					(0.0729)	(0.0881)
Home Country GDP growth						0.00159
						(0.00447)
Home Country Inflation						-0.0132*
						(0.00731)
Hansen J-Statistic	2.509	3.84	5.51	3.66	3.754	2.281
(Prob>χ^2)	.643	.437	.239	.454	.44	.6842
Anderson Rubin Wald test	43.40***	40.00***	38.5***	27.76***	26.31***	25.65***
(Prob>χ^2)	.0001	.0001	.0001	.0005	.0009	.0012
Stock-Wright S statistic	41.40***	38.09***	37.15***	26.95***	25.50***	24.83***
(Prob>χ^2)	.0001	.0001	.0001	.0007	.0013	.0017
Observations	2,472	2,472	2,088	2,088	2,088	2,088

This table presents results from panel regressions of foreign branches. The dependent variable is the real growth rate of bank lending to the real sector. We use the contemporaneous and 3 lags of the first variable, the change in: the reference group real growth rate of bank lending by regulated banks and instrument it with 7 lags of the change in the reference group banking book capital requirement. The demand proxy, real GDP growth, Inflation and enter contemporaneously and with three lags. Changes in the writeoff to asset ratio enter contemporaneously and three leads. We report the sum of coefficients and chi-square in parenthesis for these variables. For the remaining variables we report the estimated coefficients and standard errors in parenthesis. Home country KR is minimum capital requirement in the home country, official is an index of supervisory power in the home country and capital is an index of other type of capital regulation. These three variables were taken from Barth, Caprio and Levine (2008) and greater values indicate stricter regulation. Specifications 4-6 include SIZE as the log of total assets, WHL as the fraction of whole-sale funding in total assets and KAR as the total capital to total asset ratio, but these are not reported. Specification 6 includes both country fixed effects (not reported) and also the annual real GDP growth rate and inflation in the home country for the previous year (annual rates are used because for many of the home countries these variables are not available at a quarterly frequency). For statistical significance, we use the following convention throughout: *** p<0.01, ** p<0.05, * p<0.1

The International Transmission of Bank Capital Requirements: Evidence from the UK[1]

Shekhar Aiyar[2], Charles W. Calomiris[3], John Hooley[4],

Yevgeniya Korniyenko[5] and Tomasz Wieladek[6]

Abstract

We use data on UK banks' minimum capital requirements to study the impact of changes to bank-specific capital requirements on cross-border bank loan supply. By examining a sample in which each recipient country has multiple relationships with UK-resident banks, we are able to control for demand effects. We find a negative and statistically significant effect of changes to banks' capital requirements on cross-border lending: a 100 basis point increase in the requirement is associated with a reduction in the growth rate of cross-border credit of 5.5 percentage points. We also find that banks tend to favour their most important country relationships, so that the negative cross-border credit supply response in "core" countries is significantly less than in others. Banks tend to cut back cross-border credit to other banks (including foreign affiliates) more than to firms and households, consistent with shorter maturity, wholesale lending which is easier to roll off and may be associated with weaker borrowing relationships.

JEL Classification Codes: G21, G18, E51, E52, E44

Keywords: cross-border lending, loan supply, capital requirements, international transmission.

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I. Introduction

It is well documented that globalized banks transmit balance sheet shocks across borders. Cetorelli and Goldberg (2011) show that during the global financial crisis, liquidity shocks to banking systems in advanced countries caused a contraction in lending to emerging markets. Aiyar (2011) and Hoggarth, Hooley and Korniyenko (2013) document that foreign banks withdrew funding from UK-resident banks during the crisis, causing a contraction in domestic lending. De Haas and Van Horen (2013) show that cross-border retrenchment by banks was particularly severe in countries where the bank was less integrated in the local banking system. And ample pre-crisis evidence from diverse episodes and settings is marshaled by contributions such as Peek and Rosengren (1997), and Schnabl (2012).

An important instance of an externally imposed balance sheet adjustment is a regulatory change in minimum capital requirements. A separate literature has found that changes in capital requirements can trigger shifts in domestic credit supply. Several papers use cross-sectional data for this purpose, or examine changes in aggregate bank lending around the time of a regulatory regime change (see Vanhoose (2008) for a review).[1] A more recent literature focuses on a unique dataset from the UK—where the regulator imposed time-varying, bank specific capital requirements—to better identify the impulse from regulatory changes in minimum capital requirements to bank lending (Aiyar, Calomiris and Wieladek 2012, Aiyar, Calomiris and Wieladek 2013, Francis and Osborne 2012, Bridges et al 2013, Noss and Tofano 2012). All of these papers share the trait that the credit supply response analysed is purely domestic.

But there is little reason to think that the response to such a balance sheet shock would be restricted to the country in which the regulatory change originates. Indeed, the literature on the international transmission of bank liquidity shocks suggests that the response is very likely to be

[1] Chiuri et al. (2002) examine changes in bank lending behaviour around the time of a regulatory regime change. Peek and Rosengren (1995a, 1995b) and Gambacorta and Mistrulli (2004) are examples of papers that analyze cross-sectional 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.

transmitted to other countries into which the subject bank lends. The mechanism may be illustrated by considering a stylized bank balance sheet. When a bank's minimum capital requirement is raised, it can react by either raising new capital (including via retained earnings), running down any 'buffer' of capital it holds in excess of the minimum requirement, or reducing risk-weighted assets (Figure 1). To the extent that the bank reduces assets, it could either cut back on domestic assets or cross-border assets. A reduction in cross-border assets in turn, could involve cutting back on its claims on foreign-resident banks (including affiliated foreign banks), or its claims on foreign-resident non-banks (i.e. households and firms). A reduction in lending to foreign-resident non-banks directly reduces the credit available to finance real economic activity in the foreign country. A reduction in lending to foreign banks, on the other hand, is in effect a liquidity shock to the foreign country's banking system, and likely to be transmitted to the economy via a reduction in credit supplied by the (liquidity constrained) banking system.

These are not abstract concerns. In December 2011 the European Banking Authority (EBA) announced higher core tier 1 capital targets and the creation of temporary capital buffers to strengthen bank balance sheets. While important from the perspective of shoring up bank resilience, there has been much policy debate about the possible consequences of this policy measure on bank credit supply, not just within the advanced European countries where most of the EBA banks are headquartered, but also in emerging European countries (many of which are particularly reliant on credit from foreign banks) and non-European countries. While the number of banks explicitly required to raise capital under this exercise was relatively small, a greater set of banks were incentivized to strengthen their capital positions ahead of stress tests in July 2011.[2]

More generally, the recent global financial crisis has led to an increasing focus on so-called macro-prudential regulation. One element of macro-prudential regimes going forward will be time-varying minimum capital requirements on banks. These will encourage banks to build capital buffers in good times (creating greater loss absorption capacity in bad times), while also incentivising banks

[2] See the IMF's Global Financial Stability Report, April 2012 for a review.

to rein in excessive lending when the financial system is judged to be overheating. The idea is enshrined in Basel III, under which national regulators will impose a so-called counter-cyclical capital buffer on banks under their purview. In the UK, regulators can also vary banks' capital requirements on exposures to specific sectors. But such time-varying minimum capital requirements may affect not just domestic credit supply, but also credit supplied abroad. Moreover, to the extent that macro-prudential policies are co-ordinated across several advanced countries, and to the extent that emerging market countries bear a disproportional share of the cross-border adjustment associated with a capital requirement increase in advanced countries, financial spillovers to emerging markets which have relationships with several advanced country banking systems could be particularly severe.

In this paper we examine whether a rise in minimum capital requirements on UK banks is transmitted to foreign economies through a change in the supply of cross-border credit. The UK provides an ideal testing ground for the analysis, for at least two reasons. First, UK-resident banks tend to be very globalised, not just through affiliated banks abroad, but also through cross-border lending and liabilities. Cross-border lending accounted for a substantial 26% of the total lending of UK-owned banks and foreign subsidiaries resident in the UK in 2006 (the end of our sample period) and the average bank had cross-border credit outstanding in 65 countries. Figures 2-4 give some idea of the scale and geographic dispersion of cross-border lending by UK banks.

Second, during the 1990s and 2000s the UK regulator, the Financial Services Authority (FSA) imposed individual bank-specific, time-varying minimum capital requirements on the banks under its purview. This apparently unique regulatory regime is elaborated in Section II. Here we simply note that the extent of variation across banks in the minimum required risk-based capital ratio was large (the minimum required capital ratio was 8%, its standard deviation was 3.1%, 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. Merging these regulatory data with detailed data on each bank's cross-border lending creates a unique database that is ideal for identifying the cross-border credit supply impact of minimum capital requirements. In particular, we can observe quarterly cross-border lending by each bank to up to 145 countries.[3] The detailed recipient country-level data allow us to control for demand with fixed effects – a variation of the firm-level approach developed by Khwaja and Mian (2008) - and therefore give a loan supply interpretation to our estimates.

To preview our main results, we find that a change in minimum capital requirements indeed elicits a robust cross-border supply response by affected banks: a 100 basis point increase in the capital requirement is associated with a reduction in the growth rate of cross-border credit of 5.5 percentage points. Overall, this is broadly similar to the effects of between 5.7% and 7.6% reported in studies that focus on the transmission to the domestic credit supply (Aiyar, Calomiris and Wieladek, 2012). We also find that banks tend to favour their most important country relationships, so that the cross-border credit supply response in "core" countries – defined as countries that tend to be important destinations for cross-border lending from the perspective of the individual bank – is significantly less than in others. While longer maturity bank lending to non-OECD countries carried a higher risk-weight under Basel I, we do not find any evidence that banks cut bank lending more to these countries in response to a capital requirement change.[4] Together, these two findings suggest that banks' core market relationships are more important than differences in the regulatory treatment of loans for understanding which parts of the loan portfolio bear the brunt of adjustment to changes in home country regulatory requirements. Furthermore, we find that banks tend to cut back cross-border credit to other banks (including foreign affiliates) rather than to firms and households. That observation is consistent with a greater willingness, or ability, to cut back on shorter maturity, wholesale lending. This implies that an important part of the cross-border transmission of capital requirements occurs through a liquidity shock to foreign banking systems. We do not find a significant impact on direct cross-border credit to non-banks (i.e., firms and

[3] The average bank in our sample has cross-border lending relationships with 65 countries.
[4] The difference in risk-weights only applies to lending with greater than one-year maturity. See Avramova and Le Leslé (2012) for a discussion of risk weights under Basel I.

households). Although our empirical methodology and identification strategy differs somewhat from prior studies of domestic credit supply reactions to changes in capital requirements (e.g., Aiyar, Calomiris and Wieladek 2012), the magnitude of response we find in cross-border loan supply is roughly comparable to the magnitude of response in the supply of credit to domestic non-bank borrowers.

In the remainder of the paper, we proceed as follows: Section II briefly describes the bank-specific UK database that we employ to measure changes in capital requirements and changes in loan supply and loan demand. Section III describes the regression framework that we use in our investigation in greater detail. Sections IV presents the results. Section V concludes.

II. UK Capital Regulation, 1998- 2007

Our empirical analysis is made possible by a regulatory policy regime that set bank-specific, time-varying capital requirements in the UK. These minimum capital requirement ratios were set for all banks under the jurisdiction of the FSA – that is, all UK-owned banks and resident subsidiaries of foreign-owned banks. Bank capital requirements are not public information. We collect quarterly data on capital requirements, and other bank characteristics, from the regulatory databases of the Bank of England and FSA. Our sample comprises 97 regulated banks (30 UK-owned banks and 67 subsidiaries of foreign-owned banks resident in the UK). Branches of foreign-owned banks resident in the UK do not maintain separate capital from their parent group and so are excluded from the sample. 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.[5]

[5] The data used in this study exclude outliers based on the following criteria: (1) trivially small banks that do not meet the reporting thresholds for either total assets (currently £3,000,000,000) and/or cross-border claims (currently £300,000,000); and (2) observations for which the absolute value of the log difference of lending in one quarter exceeded 2.

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. For more details on the manner in which trigger ratios were set, and the consequences for banks of that variation, see Francis and Osborne (2009) and Aiyar, Calomiris, and Wieladek (2012).

As Table 2 and Figure 5 show, the variation in minimum capital requirements as a share of risk-weighted assets over the sample period was large. The median capital requirement ratio was 11%, the standard deviation 3.1 , the minimum value 8%, and the maximum value 23%. As Figure 6 shows, changes in capital requirements ratio varied significantly over the business cycle, too. Average non-weighted capital requirement ratios ranged from a minimum of 11.4% in 1998 to a maximum of 12.2% in 2005. This is a striking amount of counter-cyclical variation given that the sample period was one of varying positive growth, but no actual recessions.

Importantly, the FSA based regulatory decisions on organization structures, systems and reporting procedures, rather than high-frequency financial analysis. This institutional characteristic allowed us to treat changes in regulatory capital requirements as exogenous with respect to bank-specific domestic credit supply in earlier work (Aiyar, Calomiris and Wieladek, 2012). Of course, the argument for exogeneity is much more powerful with respect to *cross-border* lending to individual countries, since lending to any given foreign country is typically a small fraction of a UK-resident bank's portfolio. The FSA's approach to supervision was implemented via a regulatory framework known as ARROW (Advanced Risk Responsive Operating frameWork). In his review of UK financial regulation following the global financial crisis, Lord Turner, Chairman of the FSA, noted that most of the supervisory focus was on systems and processes rather than business risks and sustainability (Turner 2009). Similarly, the inquiry into the failure of the British bank Northern Rock revealed that ARROW did not require supervisors to engage in financial analysis, defined as information on the institution's asset growth relative to its peers, its profit growth, its cost to income ratio, its net interest margin, or its reliance on wholesale funding and securitisation (FSA 2008). This approach to bank regulation suggests that bank-specific lending growth or loan quality were not the main determinants of FSA regulatory decisions about capital requirements.

Aiyar, Calomiris and Wieladek (2012) consider the extent to which capital requirements were binding on bank behaviour, based on the co-movements between weighted capital ratios and weighted capital ratio requirements over time, with banks sorted into quartiles according to the buffer over minimum capital requirements that they maintain. For all four groups of banks, the variation in minimum capital requirements was associated with substantial co-movement between minimum requirements and actual capital ratios, confirming the conclusions of Alfon et al (2005), Francis and Osborne (2009), and Bridges et al. (2013) that capital ratio requirements were binding on banks' choices of capital ratios for UK banks during this sample period.

III. The International Transmission of Capital Requirements

We aim to estimate the following benchmark model (1) on quarterly data, with lending by FSA-regulated bank *i* to country *j* at time *t* as the dependent variable:

$$\Delta l_{ijt} = \sum_{k=0}^{K} \beta_{t-k} \, \Delta KR_{it-k} + \Psi G_{it} + \Lambda F_{jt} + e_{ijt} \qquad (1)$$

where Δl_{ijt} is the growth rate of lending by bank *i* to country *j* at time *t*. This comprises bilateral cross-border lending by the UK-incorporated FSA regulated entity. ΔKR_{it} is the change in bank i's minimum capital requirement (in percent of risk-weighted assets) in quarter *t*. Several lags of this term are included to allow lending to adjust gradually to changes in the regulatory ratio. *G* is a matrix of bank-specific characteristics such as size and liquidity. F is a matrix of country-specific time fixed effects to account for demand shocks in each country.

This simple design has one particularly noteworthy feature. F_{jt}, the country-specific time fixed effects, is a way of asking whether the *same* country in the *same* time period borrowing from multiple UK-incorporated banks experiences a larger decline in lending from the bank facing a relatively greater increase in minimum capital requirements. This term is therefore the direct analogue of the firm-specific fixed effects methodology pioneered by Khwaja and Mian (2008) to absorb changes in demand conditions. Since the comparison is across banks for the *same* country in a *given* time period, all demand shocks in country *j* at time *t* should be absorbed by this term.

It should also be emphasized that this study focuses on changes to minimum capital requirements imposed on *UK-resident entities*. That is, we study regulatory changes imposed at an unconsolidated level, not at a consolidated (banking group) level. This focus reflects a limitation of our data, which permit us to study international transmission via the *cross-border* lending channel of UK-resident entities, rather than examining all the sources of credit supplied to a country by the banking group (which could include credit extended by affiliated banks locally in the recipient country). Of course, the full extent of the financial spill-over to a recipient country would involve changes in both cross-border credit supply by the UK-resident bank *and* local credit supply by resident affiliates, if any. We also abstract from the issue of whether, from the recipient economy's point of view, cross-border lending by UK banks could be substituted by credit provision from other banking systems or by capital markets. Substitution by both unaffected banks and non-banks is of course possible, but a detailed investigation of this is outside the scope of this study. We do, however, explore the extent to which our estimated effects differ systematically for banks that have affiliated presence (including its headquarters) in recipient countries by including a dummy variable that takes the value of one when the destination country contains a bank branch or subsidiary that is affiliated with the bank operating in the UK. And we explore the extent to which the size and capital position of the parent bank might affect the credit supply response by the UK-incorporated bank.

In order to examine whether the impact of changes in capital requirements differs with recipient country and bank characteristics, we estimate model 2 below.

$$\Delta l_{ijt} = \sum_{k=0}^{K} \beta_{t-k}\, \Delta KR_{it-k} + \delta Z_{ijt-1} + \sum_{k=0}^{K} \gamma_{t-k}\, \Delta KR_{it-k} Z_{ijt-1} + \Psi G_{it} + \Lambda F_{jt} + e_{ijt} \quad (2)$$

The only difference between model (1) and (2) is that Z_{ijt-1} now enters in levels and as an interaction term with the change in the capital requirement ratio to assess whether the loan supply contraction varies with country and bank characteristics. Z_{ijt} contains the following variables: i) dummy variables that take the value of one when the size of a bank's lending to a country as a proportion of its total cross-border lending is in the top (*CORE*) or bottom (*PERIPHERY*) 10% of *all* cross-border lending relationships in our sample, and zero otherwise;[6] ii) a dummy variable that takes the value of one when the destination country is the bank's home country and zero otherwise; iii) a dummy variable that takes the value of one when the destination country is an OECD country and zero otherwise; iv) a dummy variable that takes the value of one when the bank is headquartered outside the UK and zero otherwise; and v) variables measuring the size and capital position of the banking group to which the UK-resident bank belongs.

The interaction of changes in capital requirements and the variables contained in Z_{ijt} allows us to explore if there is any heterogeneity in loan contractions by bank and country characteristics. In particular, it may be that the liquidity shock imposed by a capital requirement does not lead to a proportionate reduction in the bank's lending activities in all countries, but that lending to non-core countries is pared back first. This would be consistent with empirical evidence that banks scale back non-core lending disproportionately in response to liquidity shocks (Aiyar (2011), de Haas and Lelyveld (2010), Cetorelli and Goldberg (2012)). Our prior is therefore that the interaction term will be positive (that is, lending growth will fall by *less* to a core country relative to a non-core country, when the minimum capital requirement on bank *i* is raised). A different margin arises with respect to lending into OECD and non-OECD countries. Since longer maturity lending to banks in OECD countries carries a smaller risk-weight than this type of lending to non-OECD countries, one might expect a larger cutback in lending to the latter. Lending to the home country may also respond

[6] The CORE dummy is constructed using the following three step procedure. For each bank i, the variable COUNTRYSHARE is defined as bank i's lending to country j as a percentage of its total cross-border lending. The upper 10th percentile from the distribution of COUNTRYSHARE across all banks and and countries is then used as a threshold to define the CORE dummy variable (4% in our data). Bank country pairs are assigned the value 1 if COUNTRYSHARE is greater than 4% and zero otherwise.

differently to capital requirement changes than lending to other countries. The lending response may be different for foreign and UK- headquartered banks. Finally, many banks in our sample are part of larger banking groups, which may have operations in several jurisdictions outside the purview of the FSA. To the extent that such banking groups operate internal capital markets to smooth shocks to capital or liquidity between component parts (Cetorelli and Goldberg (2011), de Haas and Lelyveld (2010)), it may be that banks belonging to larger and better capitalized banking groups need to adjust credit supply less in response to changing capital requirements.

We also look at which borrowers are subjected to a cutback in credit supply arising from an increase in UK capital requirement, dividing the recipients of cross-border credit into banks and non-banks. Differences in the magnitude of loan-supply responses for different types of borrowers may reflect differences in the strength of cross-border relationships (e.g. interbank relationships may be less valuable than non-financial relationships) or differences in maturity of lending (short-term loans can be rolled off more easily). Furthermore, it is useful to distinguish between the loan-supply responses for interbank and non-bank cross-border lending because the mechanisms through which these shocks are transmitted to the recipient foreign countries' economies will differ. If the cutback in lending is to non-banks (firms and households), the impact on credit supply in the foreign country is direct, whereas if the cutback in lending is to banks, then the transmission is indirect, via a liquidity shock to the foreign banking system.

Finally, because the presence of an affiliated bank in the destination country may affect the size of adjustment in credit supply for cross-border lending (as discussed above) we include a dummy variable to capture whether the loan-supply effect in cross-border lending from banks operating in the UK differs depending on whether the banking group operating a UK bank has a presence in the destination country.

IV. Results

Prior to describing our regression results, a casual examination of the data reveals several interesting stylized facts. In levels, both external assets and lending substantially increased from 2002 onwards. But this masks an important difference: Figure 7 shows that larger banks were responsible for most of this increase in external lending. Interestingly, larger banks lend on average a lower share of their external portfolio to any given country (Figure 8), so they tend to be more diversified. Similarly, UK owned banks, which tend to be larger than foreign subsidiaries, tend to be exposed to more countries (Figure 9) and lend on average less to each country (Figure 10).

The geographical distribution of lending by UK-regulated banks reveals some additional interesting facts as well. Looking at the share of a given country in UK-regulated banks' total external lending in 2006, it seems that UK-regulated banks as a whole largely lend to North America, Western Europe, South Africa, Japan and Australia (Figure 2). On the other hand, the average exposure to a given country by a UK regulated bank is concentrated mostly in the USA, Western Europe and Japan (Figure 3). This difference between average and total lending suggests that lending to South Africa, Canada and Australia seems to be driven by a few large banks that are regulated in the UK. These were also the countries which experienced some of the largest growth in the period between 1999 and 2006 (Figure 4).

Figure 11 provides a graphical illustration of the way UK banks in our sample responded – along various dimensions – to an increase or decrease in their minimum capital ratio requirements. In constructing the graph, we capture the responses of risk-weighted assets, domestic loans, cross-border loans, and the capital buffer (the difference between the actual capital ratio and the required ratio) to changes in capital requirements. The responses to capital requirements are normalised for graphical purposes into responses to a positive 100 basis point-equivalent change. For example, we multiply the responses to a negative 100 basis point change by minus one, and we multiply the responses to a 50 basis point increase by two. As Figure 11 shows, both cross-border and domestic loans fall when capital requirements are raised. The capital buffer also falls, by more than half the size of the capital requirement increase. Risk-weighted assets fall slightly, with most of the adjustment within risk-weighted assets occurring in lending. Both domestic and cross-border lending decline sharply.[7] We emphasize that this is a descriptive graph, not a regression. The graph cannot be used to derive causal inferences (it is not an impulse response function in the conventional sense). Still, these patterns are roughly consistent with earlier research and with our own regression findings reported below.[8]

We now turn to a discussion of our regression results, which are presented in Tables 3-5. For our main variable of interest, the change in capital requirements, we report the sum of the coefficients associated with the contemporaneous and three lagged values. The figures in brackets for this variable are the p-values associated with F-test statistic for the null-hypothesis of no statistical significance. The figures All standard errors are clustered by bank and time.[9] Importantly, following the approach presented in Khwaja and Mian (2008), we include country-time fixed effects in each specification to absorb demand conditions in each country. The adoption of this framework therefore allows us interpret the estimated sum of coefficients on the change in the capital requirement ratio as a loan supply effect.

It should be noted that we regress credit growth on the change in minimum capital requirements expressed in basis points, not the percentage change in the minimum capital requirement. That is, an increase in the requirement from 11 to 11.5 percent of RWA is measured on the right-hand side of our equations as a 50 basis point increase, rather than as a 4.5% increase. Moreover, an increase in the requirement from 11 to 11.5 percent is treated the same as, say, an increase in the requirement from 2 to 2.5 percent (which is, of course, a much larger *percentage* increase in the requirement). There are a couple of reasons for this choice. First, policymakers are

[7] Note that, based on the median 11% capital requirement, a 100 basis point increase is roughly a 9% increase; if all the adjustment were occurring in risk-weighted assets, with no decline in the buffer, and no increase in capital, the total decline in risk-weighted assets would have to be about 9%.

[8] See Aiyar, Calomiris and Wieladek (2013) for a panel VAR analysis of domestic loan growth and changes in capital requirements.

[9] All results are robust to an alternative clustering of standard errors by country and time.

typically interested in the credit supply impact of raising or lowering capital requirements by a certain amount of basis points rather than in the elasticity per se. Second, and more important, in practice minimum capital requirements do not range freely from zero to 100; they are quite tightly distributed within a range of about 8 – 15 percent of RWA (Table 1). So as a practical matter an identical change in capital requirements in basis points for two banks is likely to be very similar in percentage terms too. We check this by running all key specifications in elasticity terms (available on request), and confirming that the results are very similar, but focus here on presenting the results in more intuitive units.

The regression results for model (1) are shown in Table 3. The sum of coefficients on the change in capital requirements in column (1) is -6.76, which is statistically significant at the 1% level, suggesting that total foreign lending growth falls by -6.76 percentage points over a four quarter period following a 100 basis points rise in the banks' capital requirement. Once bank fixed effects are added, which proxy for unobservable time-invariant bank specific characteristics, this effect falls to -5.48 pp (column 1a).

While country-specific demand shocks and bank-specific shocks should be picked up by the country-time fixed effects and bank fixed effects, two other standard potential problems in estimating loan supply responses to bank-specific regulatory changes remain: reverse-causality and omitted variables bias. An important advantage of our econometric approach is that concerns on the first score are largely eliminated. As discussed in section II, it is very unlikely that UK regulators were changing banks' capital requirements based on changes in external lending growth to any particular country.[10] However, we also test for this by regressing changes in capital requirements on changes in total-cross lending by bank *i* to country *j* at time *t*, including 3 lags. As expected there is no significant relationship between these variables in the opposite direction. But omitted variable bias could still contaminate our inference. For this reason we include a large number of bank balance

[10] Indeed, the ARROW framework suggests that minimum capital requirements were varied based on operational and managerial criteria rather than considerations of even domestic loan growth, let alone consideration of cross-border loan growth to a particular foreign country.

sheet control variables in columns 2, 2a and 2b. Aiyar, Calomiris and Wieladek (2012) found that changes in write-offs and their leads (as a proxy for loan quality) are important control variables, when attempting to identify the loan-supply response to changes in capital requirements. Lags and leads of changes in the write-off-to-risk-weighted asset ratio are therefore also included in specifications 2 and 2a. The inclusion of leads of write offs, however, substantially reduces the sample size for estimation. For that reason, we only include leads in one specification to investigate whether its inclusion affects the estimated coefficient of interest on the capital requirement change. As a comparison of the coefficients on capital requirement change in columns (2a) and (2b) shows, the coefficient of interest is not affected by the inclusion of leads of write offs; the decline in the magnitude of the capital requirement coefficient in columns (2a) and (2b), therefore, is the result of the substantial reduction in the sample size that occurs when leads of write offs are included.

The significance of the capital requirement coefficient is also robust to different exclusion criteria for outliers and alternative clustering techniques (see the Appendix).

Our data also allow us to split total cross-border lending into two parts: loans to banks, and loans to non-banks. Table 4 presents regressions using different definitions of the dependent variable: total cross-border lending, bank–to-bank cross-border lending, and cross-border lending to non-banks, which are shown in columns 1, 2 and 3, respectively. It should be noted that there is a substantial loss of observations when one switches from studying total lending to studying lending to banks or to non-banks separately. There are two reasons for this. First, there is a large number of zero stock observations for both bank and non-bank lending, which result in missing values for loan growth rates. Second, our specifications require multiple lags for the explanatory variables, which tends to amplify the number of observations that must be dropped due to any data gaps in the time series. With that caveat in mind, only cross-border lending to banks shows a negative and statistically significant response to changes in the capital requirement. This suggests that the overall contraction in cross-border lending is driven by lending to banks, not direct lending to firms and households. One explanation for this pattern is that bank to bank lending is typically of much shorter maturity than bank to non-bank lending, and hence easier to cut back.[11]

In columns 1a, 2a and 3a of Table 4 we test to see whether the loan-supply effect differs between destination countries that contain affiliates of banks with UK operations. Unfortunately, our data do not separate cross-border lending to banks into lending to affiliate vs unrelated banks. We therefore collect information on the locations of foreign affiliates for the banks in our sample and construct an 'affiliate' dummy variable which takes the value one if the bank has an affiliate bank (either subsidiary or a branch) in country A, and zero otherwise. We find no significant interaction effect associated with the presence of affiliates. This suggests that banks do not differentially adjust their cross-border lending depending on the global structure of their banking groups. One possible reason for this is that cross-border lending to related and unrelated banks received the same risk weight under Basel I.

Finally, Table 5 estimates model (2) to examine whether the cross-border loan contraction differs by either bank or recipient country characteristics. Columns 1-4 include both the level and the interaction term with the change in the capital requirement ratio of the following variables: i) dummy variables that take the value of one when the size of a bank's lending to a country as a proportion of its total cross-border lending is in the top (*CORE*) or bottom (*PERIPHERY*) 10% of *all* cross-border lending relationships in our sample, and zero otherwise; ii) a dummy variable that takes the value of one if the bank is a subsidiary of a foreign bank in the UK and zero otherwise; iii) a dummy variable that takes the value of one when the destination country is the bank's home country and zero otherwise; iv) a dummy variable that takes the value of one when the destination

[11] In an attempt to conserve observations while splitting the sample, we experimented with an alternative formulation; one in which the LHS variable is defined as, respectively, the increase in lending to non-banks as a proportion of *all* cross-border lending in the previous period, and the increase in lending to banks as a proportion of *all* cross-border lending in the previous period. Because the denominator is the same for lending-to-banks and lending-to-non-banks, this avoids a loss of observations across sub-samples. However, many of the observations in the lending-to-banks sample are zeros, and it is well-known that OLS estimates become severely biased in this situation. In the empirical trade literature, researchers often adopt the Poisson pseudo-maximum likelihood (PPML) estimator (Santos Silva and Tenreyro (2006, 2011), Westerlund and Wilhelmsson (2011)). Unfortunately, to the best of our knowledge, techniques have not been developed to apply the PPML in conjunction with two-way fixed effects, as required in our work.

country is an OECD country and zero otherwise. Columns 6-7 include both the level and the interaction term with the change in the capital requirement ratio of the variables measuring the size and capital position of the banking group to which the UK-resident bank belongs. As discussed in the previous section, one might expect lending to be cut back less in core countries, in OECD countries, to the home country and from larger and better capitalised banks in response to a change in capital requirements.

The regression results in Table 5 (columns 1 and 5) show that the interaction with the core dummy is statistically significant with the expected positive sign. This suggests that the cross-border loan supply contraction to 'core' countries is smaller, in accordance with our prior. None of the other interaction terms are statistically significant. The lack of statistical significance on the OECD interaction term is particularly interesting, as risk-weights on lending to banks in OECD countries are smaller. Overall this suggests that the most important source of heterogeneity in country-specific loan supply responses seems to be the magnitude (and hence relative importance) of the lending relationship with a particular country, as opposed to regulatory incentives such as risk-weights. Columns 6, 7 and 8 examine the impact of parent banks' size and capitalization. The variable *Parent Size* is the ratio of the assets of the whole banking group to the assets of the UK-incorporated bank, while *Parent Capitalization* is the ratio of the banking group's total capital to the eligible capital of the UK-incorporated bank. While the positive sign of these interaction terms is consistent with the operation of an internal capital market – belonging to a large and better capitalized banking group reduces the credit supply impact of changes in capital requirements – these estimates are not significant.[12]

[12] Note that in specifications 6 through 8, the CORE interaction becomes insignificant. This may be related to the fewer observations in these specifications, and specifically, to a disproportionate reduction in the number of smaller UK banks in the sample. This arises because data on the size and capital position of banking groups is obtained from Bankscope, which lacks data on some smaller UK banks. If smaller banks tend also to be less diversified, then core countries might be more important for this set of banks (as opposed to larger, more diversified banks).

V. Conclusion

Economists have been interested in the international transmission of domestic economic policy decisions since at least Smith (1776). There is indeed a large academic literature examining the cross-border spillover effects of monetary and fiscal policy. But the cross-border impact of a key prudential instrument - bank minimum capital requirements – has not yet been explored, despite the well-documented globalization of banking systems. This gap in our knowledge assumes even greater importance with the advent of Basel III, under which central banks and regulators around the world will impose time-varying capital requirements as a new policy instrument.[13] In this paper we make a first step towards filling this gap.

For this purpose, we exploit a unique regulatory environment extant in the UK prior to the global financial crisis: To account for deficiencies in Basel I, UK regulators adjusted capital requirements by bank and over time. Together with country-specific external lending data for these regulated banks, this allows us to examine the impact of changes in domestic capital requirements on cross-border loan supply. Because we observe lending by each bank to up to 145 different countries at each point in time, we follow the approach in Khwaja and Mian (2008) and include country-time fixed effects in each specification to absorb changes in demand conditions in each country.

We find that a 100 basis point increase in the minimum capital requirement is robustly associated with a reduction in cross-border credit growth of 5.5 percentage points. This is of a similar magnitude to estimates reported in other studies focusing on the transmission to domestic credit supply (Aiyar, Calomiris and Wieladek, 2012, Bridges et al, 2013). Lending to core countries (defined by the relative magnitude of the lending relationship) tends to reduced by less, while there

[13] Strictly speaking, we consider a bank's reaction to changes in only its own (micro-prudential) capital requirement. This is different from the approach in Basel III, where all banks will be subject to the same (macro-prudential) capital requirement. This may make a difference for the transmission to domestic credit supply, as other domestic banks which are unaffected by the micro-prudential, but would be affected by the macro-prudential, change can become a source of substitution. But this distinction is much less likely to matter for cross-border credit supply, since it is unlikely that many domestic banks compete with each other in a given recipient country.

is no evidence that lending to OECD countries, despite lower risk-weights on bank lending than in non-OECD countries, is differentially preserved. This suggests that business model considerations dominate pure regulatory arbitrage incentives. Furthermore, banks tend to cut back cross-border credit to other banks (including foreign affiliates) rather than to firms and households, suggesting that cross-border spillovers are transmitted primarily through a liquidity shock to the foreign banking system.

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Table 1: Variable definitions

Variable	Definition	Source	Notes
Capital requirement ratio	FSA-set minimum ratio for capital-to-risk weighted assets (RWA) for the banking book. Also known as 'Trigger ratio'.	Bank of England reporting form BSD3.	
Total cross-border lending	Cross-border lending by UK-resident bank i to all residents in country j.	Bank of England reporting form CC.	Includes loans, claims under repos and bills issued by non-residents.
Bank cross-border lending	Cross-border lending by UK-resident bank i to banks resident in country j.	Bank of England reporting form CC.	Includes loans, claims under repos and bills issued by non-resident banks.
Non-bank cross-border lending	Cross-border lending by UK-resident bank i to non-banks resident in country j.	Bank of England reporting form CC.	Includes loans, claims under repos and bills issued by non-resident non-banks.
Core market	Dummy variable takes the value of one when the size of lending to a country is in the top 10% of all banks' cross-border lending relationships, and zero otherwise.	Bank of England reporting form CC.	
Peripheral market	Dummy variable takes the value of one when the size of lending to a country is in the bottom 10% of all banks' cross-border lending relationships, and zero otherwise.	Bank of England reporting form CC.	
Write-offs	Write-offs (gross), per cent of risk-weighted assets.	Bank of England reporting form BSD3.	
Bank size	Log of total assets of the UK-resident entity.	Bank of England reporting form BT.	
Liquid assets	Ratio of liquid assets to total assets.	Bank of England reporting form BT.	Liquid assets include cash, bills, commercial paper and other short-term paper (in all currencies).
Stable funding	Ratio of stable funding to total non-equity liabilities.	Bank of England reporting form BT.	Stable funding includes resident sight and time retail deposits and all CDs.
Tier 1 ratio	Tier one capital as a per cent of total risk weighted assets.	Bank of England reporting form BSD3.	
Risk	Total risk-weighted assets as a per cent of total assets.	Bank of England reporting form BSD3.	
Destination country exposure	Cross-border lending by bank i to country j, as a per cent of bank i's total cross-border lending, lagged one period.	Bank of England reporting form CC.	
Foreign	Dummy variable takes the value of one when bank is a UK-resident subsidiary of a foreign bank, and zero otherwise.	Bank of England.	
Affiliate	Dummy variable takes the value of one when UK-resident bank i has a bank affiliate in country j and zero otherwise.	SNL and banks' annual reports.	
OECD	Dummy variable takes the value of one	OECD.	

	when country is a member of the Organisation for Economic Cooperation and Development, and zero otherwise.	
Parent size	Ratio of assets of the parent bank to assets of the UK-resident entity	Bank of England reporting form BT, Bankscope and banks' annual reports.
Parent capitalisation	Ratio of capital of the parent bank to the capital of the UK-resident entity.	Bank of England reporting form BT, Bankscope and banks' annual reports.

Table 2: Summary statistics

Variable	Entity	Units	Median	S.D.	Min	Max	Obs
Capital requirement ratio	All UK-regulated banks	%	11.0	3.1	8.0	23.0	2601
	UK-owned banks		9.0	1.8	8.0	17.0	956
	Foreign subsidiaries		12.5	3.0	8.5	23.0	1645
Change in capital requirement ratio	All UK-regulated banks	Basis points	0.0	38.0	-500	500	2495
	UK-owned banks		0.0	24.5	-200	500	902
	Foreign subsidiaries		0.0	44.1	-500	500	1593
Change in cross-border lending to all non-residents	All UK-regulated banks	%	0	37	-100	100	96402
	UK-owned banks		0	35	-100	100	52580
	Foreign subsidiaries		0	39	-100	100	43822
Change in cross-border lending to non-resident banks	All UK-regulated banks		-1	46	-100	100	43387
	UK-owned banks		-3	45	-100	100	21248
	Foreign subsidiaries	%	0	46	-100	100	22139
Change in cross-border lending to non-resident banks	All UK-regulated banks		0	32	-100	100	82171
	UK-owned banks		0	30	-100	100	49008
	Foreign subsidiaries	%	0	33	-100	100	33163

Table 3: The effect of changes in minimum capital requirements on UK regulated banks' cross-border lending growth

Dependent variable: UK regulated banks' cross border lending growth	1	1(a)	2	2(a)	2(b)
Change in capital requirement ratio (DBBKR) (summed lags)	-6.760***	-5.475***	-5.362***	-3.077*	-3.291*
(prob>F)	(0.000)	(0.001)	(0.003)	(0.097)	(0.085)
Bank Size			1.566	2.229**	2.217**
(p-value)			(0.111)	(0.044)	(0.047)
Liquidity			0.099	0.127	0.135
(p-value)			(0.476)	(0.405)	(0.371)
Stable Funding			-0.022	-0.003	-0.002
(p-value)			(0.290)	(0.927)	(0.941)
Tier 1 Ratio			0.015*	0.003	0.003
(p-value)			(0.074)	(0.823)	(0.822)
Risk			0.002	-0.002	-0.002
(p-value)			(0.373)	(0.730)	(0.729)
Destination country exposure			-0.147***	-0.203***	-0.202***
(p-value)			(0.000)	(0.000)	(0.000)
Change in write –offs (summed leads)				2.463*	
(prob>F)				(0.061)	
Change in write –offs (summed lags)			1.472		
(prob>F)			(0.106)		
Observations	52,683	52,683	46,946	34,854	34,854
R-squared	0.089	0.102	0.115	0.135	0.134
Quarter/Country FE	YES	YES	YES	YES	YES
Bank FE	NO	YES	YES	YES	YES

Notes: This table presents results from fixed effects panel regressions of UK-regulated banks. The dependent variable is the quarterly growth rate (FX-adjusted) of bank i's total cross-border lending (sum of lending to banks and non-banks) to country j. The contemporaneous value of the change in capital requirements (DBBKR) is used, along with three lags. The table entry for DBBKR shows the sum of these four coefficients, together with the probability that the sum is significantly different from zero according to the F-test statistic. A similar convention is followed for changes in write-offs in columns 2 and 2(a). The remaining coefficients are shown together with p-values. *, ** and *** denote significance at the 10%, 5% and 1% level respectively. A constant is included but not shown.

Table 4: The effect of changes in minimum capital requirements on UK regulated banks' cross-border lending growth: all loans/banks/non-banks

Dependent variable: UK regulated banks' cross border lending growth	1 Cross-border lending to all non-residents	1a Cross-border lending to all non-residents + affiliate dummy	2 Cross-border lending to non-resident banks	2a Cross-border lending to non-resident banks + affiliate dummy	3 Cross-border lending to non-resident non-banks	3a Cross-border lending to non-resident non-banks + affiliate dummy
Change in capital requirement ratio (DBBKR) (summed lags)	-5.475***	-4.908***	-6.110**	-5.363**	-0.882	-1.007
(prob>F)	(0.001)	(0.004)	(0.012)	(0.035)	(0.569)	(0.530)
Affiliate Dummy * DBBKR		-5.106		-4.823		0.716
(prob>F)		(0.172)		(0.356)		(0.830)
Affiliate Dummy		0.721		0.237		0.514
(p-value)		(0.144)		(0.800)		(0.239)
Observations	52,683	52,683	16,265	16,265	50,169	50,169
R-squared	0.102	0.102	0.162	0.162	0.109	0.109
Quarter/Country fixed effects	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES

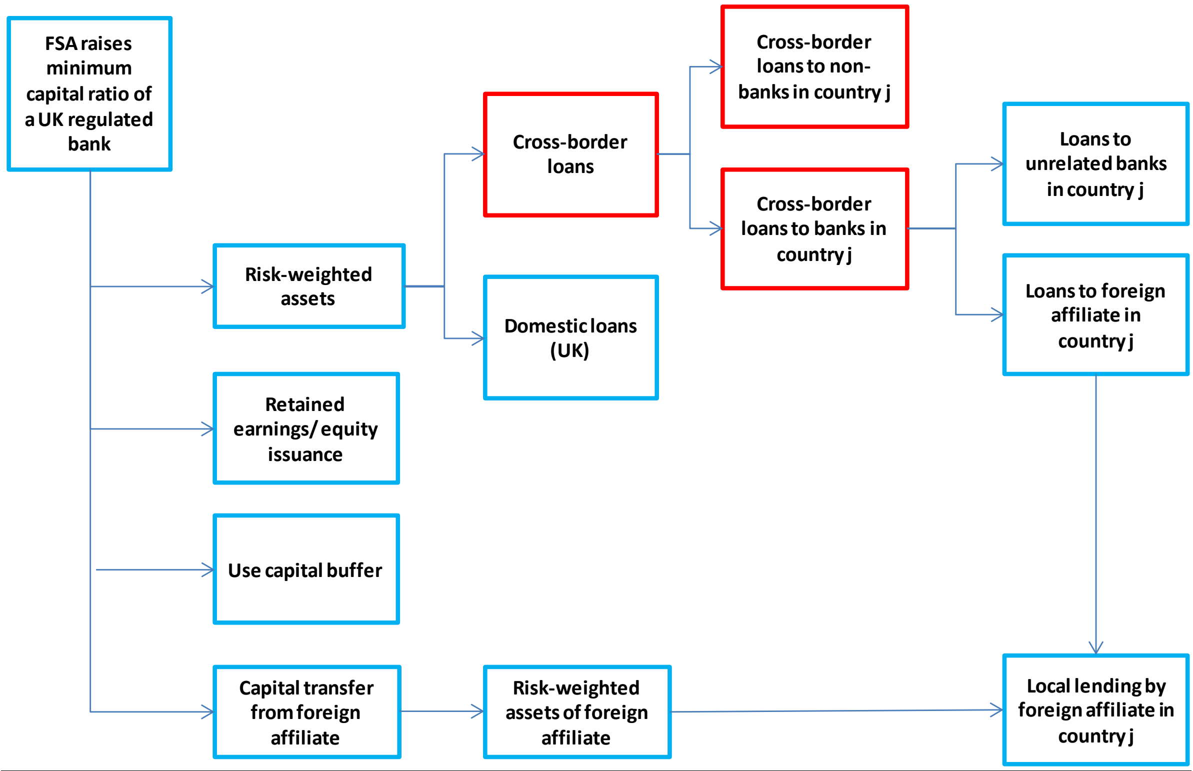
Notes: This table presents results from fixed effects panel regressions of UK-regulated banks. The dependent variable is the quarterly growth rate (FX-adjusted) of bank i's cross-border lending to all non-residents (sum of bank and non-bank) (columns 1, 1a), banks only (columns 2,2a) and non-banks only (columns 3,3a) in country j. The affiliate dummy takes the value one where bank i has an affiliate bank (branch or subsidiary) in country j and zero otherwise. The other conventions are the same as in Table 3.

Table 5: The effect of changes in minimum capital requirements on UK regulated banks' cross-border lending growth with interaction terms

Dependent Variable : UK regulated banks' cross-border lending growth	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Change in capital requirement ratio (DBBKR) (summed lags)	-6.942***	-4.195	-5.324***	-4.869***	-4.951*	-5.758***	-4.979*	-5.693*
(prob>F)	(0.000)	(0.120)	(0.001)	(0.008)	(0.083)	(0.004)	(0.053)	(0.067)
Core Market*DBBKR	6.707*				7.608**			9.176
(prob>F)	(0.057)				(0.031)			(0.228)
Periphery Market* DBBKR	7.291				6.760			6.440
(prob>F)	(0.199)				(0.229)			(0.414)
Foreign Bank*DBBKR		-1.499			-1.035			0.646
(prob>F)		(0.646)			(0.753)			(0.918)
Home country*DBBKR			-9.440		-9.791			-5.783
(prob>F)			(0.336)		(0.271)			(0.748)
OECD*DBBKR				-1.454	-2.573			-4.390
(prob>F)				(0.612)	(0.382)			(0.366)
Parent size*DBBKR						0.0851		-0.0792
(prob>F)						(0.257)		(0.716)
Parent capitalisation*DBBKR							0.0762	0.225
(prob>F)							(0.653)	(0.553)
Core Market	9.784***				10.040***			9.951***
(p-value)	(0.000)				(0.000)			(0.000)
Periphery Market	-6.432***				-6.412***			-6.207***
(p-value)	(0.000)				(0.000)			(0.000)
Foreign Bank		-2.202			-1.676			0.376
(p-value)		(0.275)			(0.404)			(0.815)
Home Country			-1.841		-5.637***			-5.281***
(p-value)			(0.262)		(0.001)			(0.006)
Parent size						0.013**		0.010
(p-value)						(0.015)		(0.308)
Parent capitalisation							0.012	0.008
(p-value)							(0.118)	(0.396)
Observations	52,683	52,683	52,683	52,683	52,683	45,733	39,853	39,853
R-squared	0.112	0.102	0.102	0.102	0.112	0.116	0.129	0.139
Quarter/Country fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Bank FE	YES	YES	YES	YES	YES	YES	YES	YES

Notes: This table presents results from fixed effects panel regressions of UK-regulated banks. The dependent variable is the quarterly growth rate (FX-adjusted) of bank i's total cross-border lending (sum of lending to banks and non-banks) to country j. Interaction terms between changes in capital requirements (DBBKR) and various bank and country characteristics are also included. The other conventions are the same as in Table 3.

Figure 1: International transmission of changes in domestic capital requirements



NB: this study focuses on the part of the cross-border lending aspect of the transmission mechanism, highlighted in red.

Figure 2: Total country share of UK regulated banks' total cross-border lending (2006)

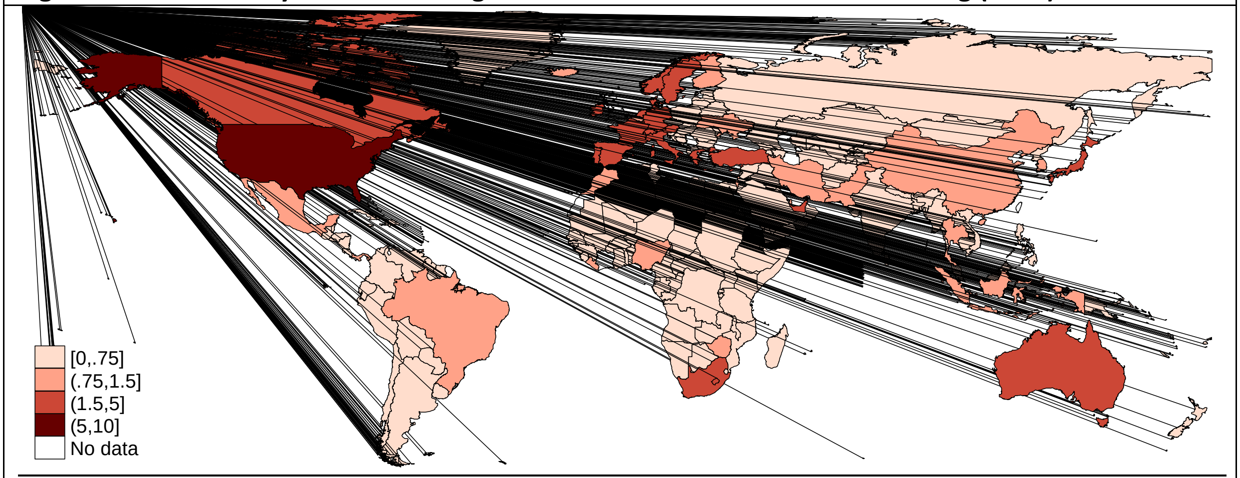


Figure 3: Mean country share (by bank) of UK-regulated banks' total cross-border lending (2006)

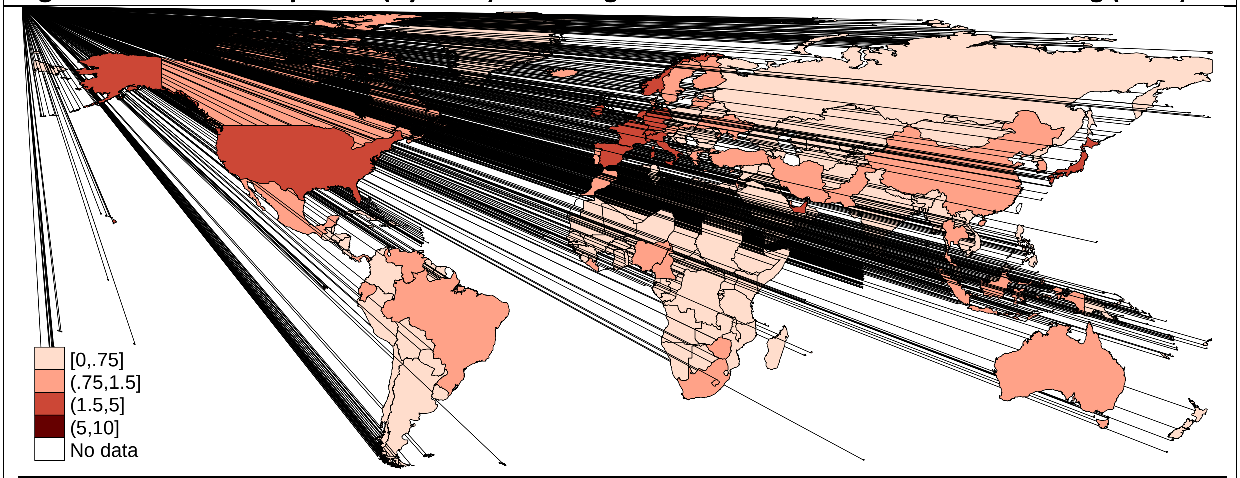


Figure 4: Growth in UK-regulated banks' total cross-border lending (1999-2006)

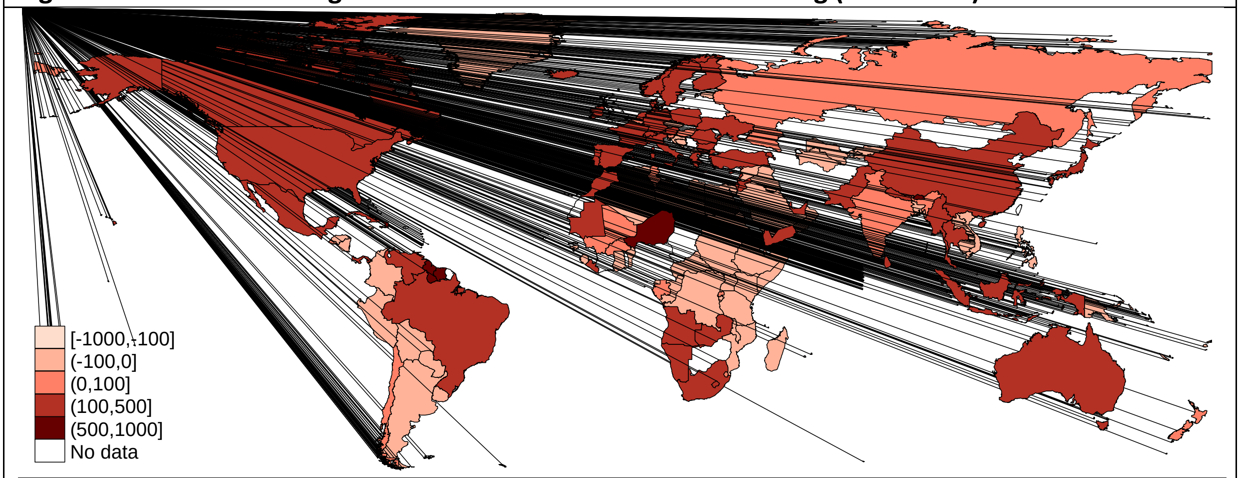


Figure 5: Histogram of minimum capital requirement ratio

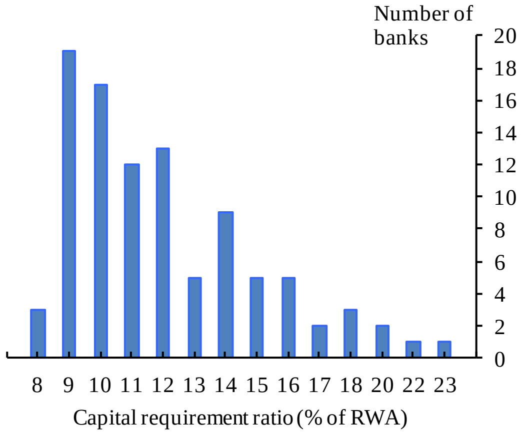


Figure 6: Capital requirement ratio and GDP growth

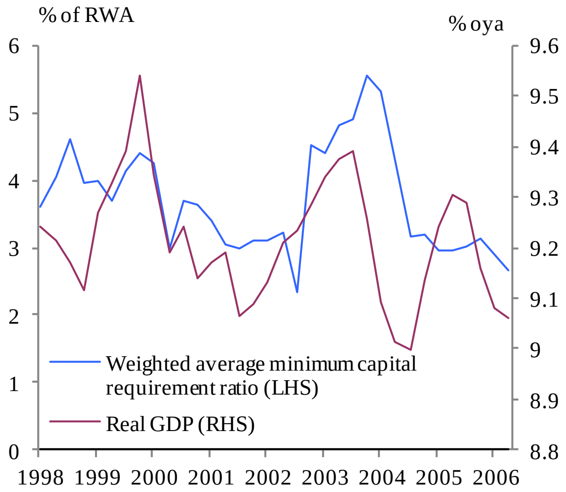
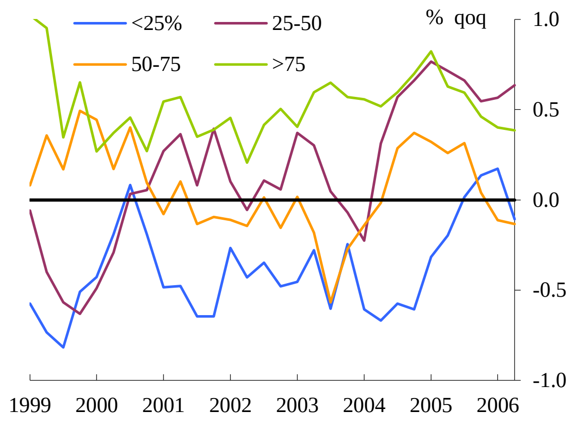
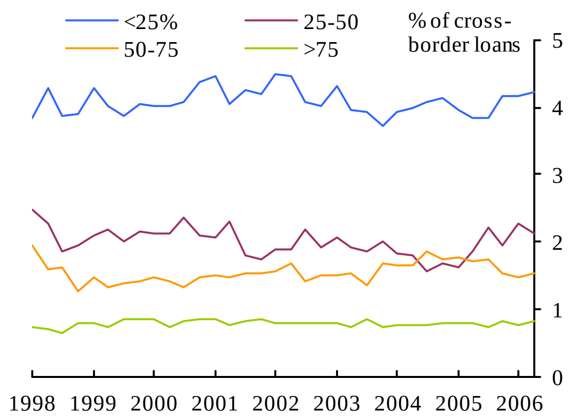


Figure 7: Cross-border lending growth by bank i to country j (by bank size, in percentiles) [(a)]



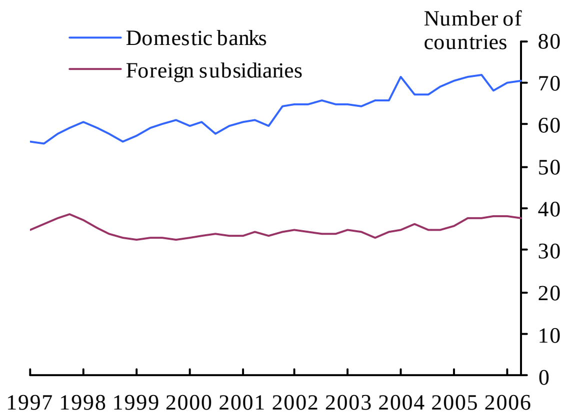
[(a)] Mean growth across the sample of bank-country pairs.

Figure 8: Loans to country j as a share of bank i's total cross-border loans (by bank size, in percentiles) [(a)]



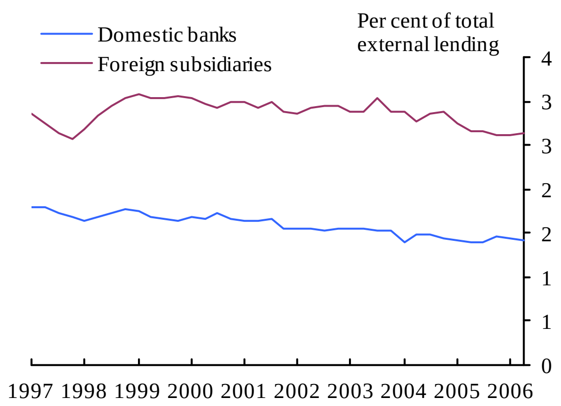
[(a)] Mean shares across the sample of bank country pairs.

Figure 9: Number of lending destinations per bank[(a)]



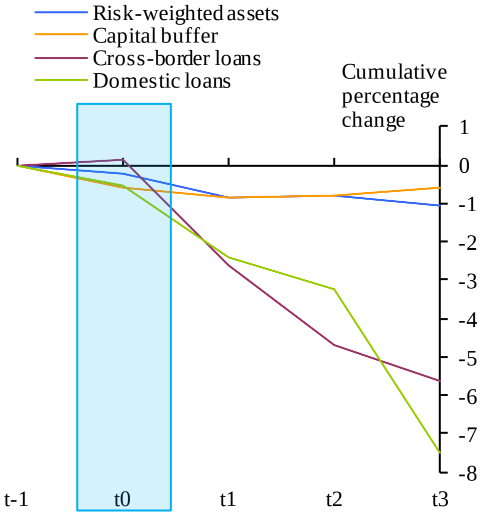
[(a)] Mean number of destinations across the sample of banks.

Figure 10: Share of country j in bank i's cross-border lending[(a)]



[(a)] Mean shares across the sample of bank-country pairs.

Figure 11: Cumulative changes in selected balance sheet variables following a 100bp increase in capital requirements



Notes: The figure shows cumulative percentage changes in domestic private sector loans, cross-border loans, risk-weighted assets and the cumulative pp change in the capital buffer, in the three quarters following a change in capital requirements (at t0). The lines show the median response across banks, to changes in capital requirements, normalised to a 100bp increase.

Appendix

A1. Data

The data used in this paper are based on the statistical returns submitted to the Bank of England by the entire population of UK-resident deposit takers, including building societies.[14] All data are unconsolidated— they refer to individual authorised banks irrespective of whether they are part of a larger banking group operating in the United Kingdom. Bank nationality is determined by where its ultimate parent (e.g. holding company) is located and not by the nationality of the largest shareholder. For example a 'UK-owned' bank simply means its ultimate parent is incorporated in the United Kingdom.

The data are processed by the Bank of England Statistics and Regulatory Data Division who conduct a methodical data interrogation process, designed to identify misreporting or errors which materially affect the data. Despite this some minor data issues remain on a bank-by-bank basis. The raw reporting data, therefore, was adjusted by the authors on a best endeavours basis. This data annex describes the data used and the adjustment procedures followed. The dataset used is quarterly from end-1998 Q3 through to end-2006 Q4. A full description of the variables used, together with the relevant reporting forms is provided in Table 1.

External lending data

The main variable of focus, external lending by bank i to country j is defined as cross-border lending from the UK-resident entity to both the financial and non-financial sectors in the foreign country. It includes lending to other banks within the same banking group (intragroup) but excludes any lending in local currencies done by bank i's foreign affiliate in country j. Lending is in all currencies and comprises loans and advances, and claims under sale and repurchase agreements..

[14] A full description of these forms can be found at: http://www.bankofengland.co.uk/statistics/Pages/reporters/default.aspx

The whole population of UK-regulated banks (i.e. UK-owned banks and foreign subsidiaries) are included that have external claims above the reporting threshold of £300mn. [15]

The raw external lending data were adjusted to account for the following: i) exchange rate movements; ii) mergers and acquisitions and iii) outliers:

Foreign currency adjustment

Information on the currency composition of the main variables of interest was used to adjust the flows data for exchange rate movements. External lending is measured in sterling. Amounts outstanding data are reported in sterling which are then converted into the 'original' foreign currency using the appropriate end-quarter exchange rates. Changes in these amounts outstanding, expressed in their 'original currency', are then converted back into sterling using the average exchange rate for the quarter.

Treatment of mergers and acquisitions

Over the period analysed, a number of the banks in the sample were involved in mergers or acquisition activity. Bank mergers were dealt with by creating a synthetic merged series of the merging banks' balance sheets over the entire period. The acquired bank was then removed from the data set.

Outliers

The data used in this study exclude outliers for which the absolute value of the log difference of lending in one quarter exceeded +/- 2.

[15] Banks omitted from the sample tended to be small or domestically focussed (e.g. building societies).

A2. Sensitivity of the results to different cleaning techniques

Below we investigate the sensitivity of our results from Table 3 to the cleaning assumptions that we have made. Due to extremely high volatility of some bank-country time series, we symmetrically restricted the growth rate of cross-border lending to country *j* by bank *i* in any given quarter to lie within the interval of -100/+100%. This is equivalent to discarding approximately 15% of the sample. The result, based on this data cleaning approach, is presented in column 1 of Table A1. Column 2 of Table A1 shows results for the same regression, but includes observations for the dependent variable within a wider interval of -200/+200%, equivalent to dropping 10% of the sample. Column 3 truncates the distribution of the dependent variable symmetrically at the 90th percentile. Finally, column 4 defines the dependent variable as the flow of cross-border lending to country *j,* by bank *i,* at time *t* divided by the stock of bank *i's* total cross-border lending at time *t-1* (as opposed to bank *i's* stock of lending to country *j* at time *t).* To account for the outliers we drop -1/+1% of the distribution. The results show that the effects estimated in columns 1-3 are broadly similar to each other. The smaller estimated coefficient in column 4 is not comparable with the estimates in columns 1-3. Instead, it must be multiplied by the average number of countries each bank lends to (65 in our sample), yielding a value of -5.98, which is not dissimilar to our baseline estimate in column 1. These findings suggest our results are robust to different data cleaning techniques.

Table A1: Robustness checks

Dependent variable: UK regulated banks' cross border lending growth	1 Base specification (used in Tables 3-5)	2	3	4
Change in capital requirement ratio (DBBKR) (summed lags)	-5.475***	-5.208***	-2.350***	-0.092**
(Prob>F)	0.005	0.002	0.006	0.045
Observations	52,683	61,944	34769	78,134
R-squared	0.102	0.083	0.14	0.036
Quarter/Country fixed effects	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES

Notes: This table presents results from fixed effects panel regressions of UK-regulated banks. In columns 1, 2 and 3, the dependant variable is the quarterly growth rate (FX-adjusted) of bank i's total cross-border lending (sum of lending to banks and non-banks) to country j. In column 4, the dependent variable is the change (FX-adjusted) of bank i's total cross-border lending to country j, as a percentage of the stock of bank i's total cross-border lending to all countries in the previous period. In each Column, a different cleaning method is used to exclude outliers from the dependent variable (see the description in section A2 of the appendix). The other conventions are the same as in Table 3.