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What determines how banks respond to changes in capital requirements?

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Saleem Bahaj,[1] Jonathan Bridges,[2] Frederic Malherbe[3] and Cian O'Neill[4]

Abstract

Legacy asset overhang and risk-shifting incentives can both affect bank capital issuance and lending decisions. We show that such frictions lead to ambiguous predictions on how one should expect a bank to react to a change in capital requirements. One sustained prediction is that lending is less sensitive to a change in capital requirements when lending prospects are good and legacy assets are healthy. Using UK bank regulatory data from 1989 to 2007, we find strong empirical support for this hypothesis.

Key words: Debt overhang, risk-shifting, bank capital, local projections.

JEL classification: G21, G32.

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1 Introduction

Financial institutions in general and banks in particular are much more leveraged than typical non-financial firms. A potential reason is that the conditions for the Modigliani and Miller theorem to hold are violated in a different way. For instance, bank creditors enjoy explicit and implicit guarantees from the government. At the same time, banks also face capital requirements. There seems to be a consensus among policymakers that levels of leverage observed before the recent crisis were excessive. Many academics share this view, but others contend that equity is "costly" and that raising capital requirements would impair lending to the real economy. A way to summarise the debate is to consider two sequential questions. First, under which conditions does a change in capital requirements affect a bank's lending decision? Second, when it is the case, to what extent does the bank adjust its capital ratio through the denominator (i.e. by a change in lending), rather than the numerator (by a change in capital)?

Our contribution to this debate is twofold. First we provide a theory of how banks choose to issue capital and lend in the presence of capital requirements. This theory generates novel empirical predictions regarding the factors that determine the effect capital requirements have on bank behavior. Our second contribution is to test these state-contingent hypotheses using data on regulatory filings for individual banks.

We start by studying the problem of a bank that chooses its level of capital and how much to lend in order to maximize initial shareholders' expected payoff. The bank starts with a given level of capital but can pay a dividend or issue new capital to deep-pocketed risk-neutral investors. Several ingredients are important for the analysis. First, the bank has legacy assets on its balance sheet and shareholders enjoy limited liability. Second, the government guarantees deposits. Third, the bank faces a capital requirement. Fourth, the bank faces a downward sloping demand for loans. That is, bank lending presents diminishing expected marginal returns, which translates to there being an efficient level of lending for the bank.

If both legacy assets and prospects are strong (i.e. generate high expected surpluses and entail little risk), Modigliani and Miller's theorem applies. The capital requirement is not a constraint on the bank's behaviour and the bank chooses to finance all the (and only the) positive net-present-value loans.

When legacy assets entail large downside risk (compared to the potential surplus from new lending), they create a debt overhang problem. Given the capital requirement, the bank does not raise enough capital (or pays too high a dividend) to reach the efficient level of lending. When new lending has sufficient downside risk (compared to both its expected surplus and that from legacy assets) to potentially lead the bank to default, government guarantees act as a subsidy to lending and may induce the bank to grant negative net-present-value loans (which can be interpreted as a form of risk-shifting). Which effect dominates, determines whether the bank underlends (i.e. forgoes positive net-present-value lending) or overlends.

Whenever Modigliani and Miller's theorem does not hold, changes in capital requirements affect lending. The sign and the strength of the effect, however, depends on the combined effect of legacy asset overhang and risk shifting. These problems generate different predictions. Under risk-shifting, an increase in capital requirements decreases the equilibrium riskiness of the bank. Lending is then affected (it is weakly decreasing in the requirement, which is good in terms of efficiency), but less so when lending generates a high surplus and is not too risky.

In the overhang case, however, there are two opposing forces in play. For a given cost of capital (and probability of bank failure), a higher requirement raises overall bank funding costs. This tends to contract new lending, which generates less surplus. Hence, this worsens the inefficiency and makes the bank more risky. However, there is also a *recapitalisation effect*. Keeping lending constant, a tighter requirement decreases the probability of default, which mitigates the overhang problem. In turn, this reduces the cost of capital and increases lending. Either force can dominate and the model's prediction is therefore ambiguous.

Whether the effect in reality is positive or negative is an empirical question. The theory, however, can shed some light on the relative strength of the relevant mechanisms. When lending is affected by a change in the capital requirements, the intensity of such effect (i.e. the share of the adjustment that is borne by lending rather than capital) depends on the Bank's situation. In particular, the model predicts that lending is less sensitive to a change in capital requirement when lending prospects are good and legacy assets are healthy.

To explore the model's predictions empirically we rely upon a feature of the UK bank regulatory regime over the period 1989-2007 under Basel I. The Bank of England and, later, the Financial Services Authority varied, over time, individual bank capital requirements for microprudential purposes. This regime has provided the literature with a unique environment to determine the dynamics of policy interventions on capital requirements. Our sample covers a panel of UK banks during this period. By merging individual institutions' monetary and prudential regulatory returns into a single dataset (as introduced in Bridges et al. (2014)), we observe banks' decisions over the quantity of their lending and regulatory capital.

We assess bank reactions to changes in capital requirements using a local projection approach (Jordà, 2005). This approach is advantageous in that it can easily be adapted to assess bank behaviour conditional on business or financial cycle variables, which allows us to construct non-linear impulse responses (Jordà et al., 2013 and Jordà et al., 2015a).

Unfortunately, we cannot directly observe lending prospects and the health of legacy assets for individual banks. Instead, we proxy such variables based on the behaviour of other banks. In short, we assume that while high credit growth in the aggregate reflects strong prospects (and a limited debt overhang problem), low credit growth reflect poorer prospects and/or a strong debt overhang problem.

Our empirical results provide strong support for our model's predictions. In the times of credit expansion an increase in a capital requirement has a minimal impact on lending but, when credit growth is weak, we estimate that a 25 basis point increase in the requirement can cause lending to fall by an extra 4%. The flip side of this is that a change in capital requirement is mainly met by capital issuance during periods of rapid credit growth. This is not the case when credit growth is weak. In fact, capital levels can even fall as banks downsize in response to a tightening of the requirement.

The rest of this paper is organised as follows, after an overview of the related literature, Section 2 presents the findings from our theoretical model. Section 3 uses the model to determine empirical predictions and outlines a strategy to test them. Section 4 presents our empirical results and Section 5 concludes.

Related literature Our paper contributes to the understanding of bank decisions over their asset and liability structure. The novelty is to consider capital requirements in a context that combines both a legacy asset overhang and a subsidy from government guarantees. Besides generating patterns consistent with the notion of an excessive credit cycle, these enable us to derive novel empirical predictions on the preferred margin of deleveraging adjustment as a function of the state of the economy. Given the nature of our data, our focus is partial equilibrium in nature: we consider how the economic situation affects a banks behaviour as capital requirements change but not the general equilibrium consequences.

Debt overhang problems (Myers 1977) have been the subject of many studies in the corporate finance literature. Following the recent crisis, a wave of papers have applied the concept to financial institutions with massive holdings of toxic assets. Tirole (2011), Philippon and Skreta (2012), and Philippon and Schnabl (2013) study how the government can best kick start lending in such a situation. Even though we also consider lemons problems, this is not our main focus. Another difference is that these analyses abstract from capital requirements, which are central to our analysis.

It is well understood that government guarantees can distort investment decisions (Merton 1977, Kareken and Wallace 1978). Typically, the problem is cast in terms of asset substitutions, or risk-shifting as in Jensen and Meckling (1976). When demand for loans is downward sloping, government guarantees are likely to induce negative net-present-value lending (see, for instance, Martinez-Miera and Suarez 2014 and Malherbe 2016). We build on this mechanism but we focus on the interaction between lending prospects and legacy assets. Furthermore, we fully endogenize bank capital issuance and retention.

Considering the key ingredients of our model, the closest paper is perhaps Admati et al. (2013). They also combine debt overhang and incentives to shift risk. However they focus on (the lack of) incentives to *voluntarily* deleverage (they do not consider capital requirements), which in a dynamic setup gives rise to a leverage ratchet effect. Some of the mechanisms they highlight play a role on why the requirements are typically binding in our analysis, but we obtain different predictions. In particular, we highlight how the chosen adjustment mix depends on economic conditions.

Our paper provides a positive analysis of bank adjustments to changes in individual capital requirements. On that dimension it relates to papers that study the loan pricing implications of capital regulation (e.g. Koehn and Santomero 1980, Rochet 1992, Repullo and Suarez 2004) and, more recently, their equilibrium consequences. Regarding these consequences, even though our empirical analysis covers the period where Basel I was in place, the insights we derive speaks to the current normative debate on capital requirements. Two of the main current focuses are (i) the optimal overall level of capital requirement (see e.g. Admati et al. 2010, Martinez-Miera and Suarez 2014; (ii) time-varying adjustments (the so-called counter-cyclical buffers, see e.g. Kashyap and Stein 2004, Repullo and Suarez 2013, Malherbe 2016).

There is a substantial empirical literature on bank responses to shocks to their capital. Bernanke and Lown (1991) use regional variation across the US to identify a role for capital losses in reducing subsequent credit provision. Peek and Rosengren (1997) identify a similar bank lending channel, by focusing on the lending behaviour of Japanese subsidiaries in the US, which suffered losses following the sharp decline of Japanese stock prices in the early 1990s.

Hancock and Wilcox (1994); Hancock et al. (1995) use time series methods coupled with data on a panel of US banks and reach similar conclusions regarding the importance of capital for bank behaviour. In contrast, using more recent US bank data, Berrospide and Edge (2010) find only modest effects of bank capital on lending, using both panel regression and VAR models. A recent strand of literature has focussed on loan-level data in order to establish a link between bank capital and lending decisions. For example, Jimenez et al. (2012) use Spanish loan-level data to demonstrate that "weak banks" with lower capital or liquidity ratios are less likely to grant a loan to a given applicant than stronger banks. Albertazzi and Marchetti (2010) demonstrate a similar result with Italian data.

Another strand of the literature, more closely related to the empirical analysis in this paper, focuses on bank responses to explicit changes in regulatory requirements. In this regard, the UK has provided a good testing ground given its history of operating time-varying capital requirements for microprudential purposes. The conclusions from this literature (see for instance Francis and Osborne (2009a, 2012); Bridges et al. (2014), Aiyar et al. (2014b,a)) are that capital requirements tend to bind (albeit subject to banks holding a voluntary buffer) and, therefore, that an increase in the requirement causes a contraction in bank assets and lending. Our empirics contribute to this literature by explicitly considering how the economic environment may influence how banks respond to changes in capital requirements.

In that regard, a final related strand is the empirical literature on the contingent impact of shocks. Auerbach and Gorodnichenko (2012, 2013) and Ramey and Zubairy (2014) explore how fiscal shocks affect the economy in recessions versus expansions. Tenreyro and Thwaites (2015) conduct a similar exercise for monetary policy. Jordà et al. (2013, 2015b,a) consider how leverage and asset prices influence the the economy's response to negative business cycle shocks and financial crises.

2 Theory

2.1 Model

There are three dates, 0,1, and 2. There is a bank and a continuum of investors. All agents are risk neutral and do not discount the future. Investors have an opportunity cost of funding of 1. We focus on the date 1 decision of the bank.

Predetermined variables. Predetermined variables can be thought of as resulting from date 0 decisions. There are legacy assets that will mature at date 2. Their book value is z. In the baseline model, they cannot be sold at date 1. These assets yield a risky payoff Z at date 2. We denote by e the difference between z and the face value of the bank's debt. Hence, e is the initial book value of bank capital.

Decision variables. The bank chooses how much capital to issue. We do not restrict seasoned capital to be a particular form of security. One can, however, think of it as subordinated debt or seasoned equity. Seasoned capital is denoted s, and the corresponding date-2 total repayment is denoted R. This repayment is determined in equilibrium and can be contingent on any observable variable. The bank also chooses how much to pay as an initial dividend d. Finally, the bank decides how much to lend. We denote the total amount of new lending by $x \geq 0$. The date-2 return from x is given by a function $F(A,x)$, which is increasing and strictly concave in x and strictly increasing in A, which is a random variable that realises at date 2 and captures the quality of lending prospects. We assume that $E[F_x(A,0)] > 1$, where $F_x(A,x)$ is the derivative of $F(A,x)$ with respect to x, so that there always are positive net-present-value lending opportunities. Finally, $F_x(A,x)$ is non decreasing in A.

Deposit taking and capital requirement. The bank can raise insured deposits that pay a zero interest rate. There is no insurance premium, but the bank faces an exogenous capital requirement that takes the form:

$$e + s - d \geq \gamma(x+z), \tag{1}$$

with $\gamma \in (0,1]$, and where $x+z$ is the total of the assets maturing at date 2, and $e+s-d$ is the bank total capital at date 1. This means that the requirement can be met with any type of capital, what matters is that it is junior to deposits and can, therefore, absorb losses. The bank cannot pay a dividend if $e+s-d < \gamma z$. However, the bank can be closed at date 1, in which case initial shareholders walk away with 0. This means that bank must satisfy (1) only if it keeps operating.

Default. Assuming, without loss of generality, that the bank does not hold cash, the amount of deposits needed to fund an amount of lending x is $x+z-e-s+d$. Denoting V the net worth of the bank at date 2, we have:

$$V \equiv F(A,x) + Z - \underbrace{(x+z-e-s+d)}_{deposits}.$$

Because of limited liability, the corresponding net worth of bank capital is $\max\{0,V\}$. When $V<0$, the bank defaults on deposits and no payment to other liability is allowed.

Seasoned capital. The bank's repayment to seasoned capital investor is bounded below by 0 (investors in seasoned capital have limited liability) and above by V (deposits are senior and initial shareholders have limited liability). That is:

$$0 \leq R \leq \max\{0,V\}. \tag{2}$$

We assume that investors act competitively and that they have deep enough pockets, so that, in equilibrium, they just break even in expectation. That is:

$$E[R] = s. \tag{3}$$

Information structure We first consider the case where the bank and investors know the distribution of Z and A. In Section 5, we introduce an adverse selection problem: we assume that investors do not know the true distribution of Z. What we want to capture, in a reduced form fashion, is that banks are likely to be better informed about the quality of their asset in place than outsiders. In that case, we assume that there may be a stigma to issuing seasoned capital, and we adapt condition (3) accordingly.

Bank closure. If initial equity is low, legacy assets yield low return, and prospects are not good enough, it may not be feasible to satisfy both the capital requirement and the investor break-even constraint. In such a case, bankers choose to close the bank and walk away with nothing. This case is interesting per se, but not so relevant for our main purpose. We, therefore, assume that the bank can, and chooses to, operate.

2.2 Baseline analysis

Assuming the bank operates, the expected payoff to initial shareholders is:

$$E^{+}[V-R]+d,$$

where $E^{+}[Y]$ denotes $E[\max\{0,Y\}]$.

Since $0 \leq R \leq \max\{0,V\}$, we have that $R=0$ in states where $V \leq 0$. Hence, we have:

$$E^{+}[V-R]=E^{+}[V]-E[R].$$

2.2.1 The maximization problem

Seasoned capital investors' break even condition is $E[R]=s$. Hence, the programme of the banker can be written as follows:

$$\max_{x,s,d\geq 0} E^{+}[V]-s+d,$$

subject to the capital requirement (1).

Given the structure of the model, there is no reason for banks to hold capital buffers in excess of the requirement.

Lemma 1. *In all cases where the Modigliani-Miller theorem does not hold, the bank prefers, at the margin, to fund lending with deposits rather than capital.*

Proof. See the Appendix. □

Accordingly, we assume that the capital requirement is always just satisfied.[1]:

$$s=\gamma(x+z)-e+d,$$

and total deposits is given by: $(1-\gamma)(z+x)$.

Given that seasoned capital is issued at fair value ($E[R]=s$), paying a dividend corresponds to a negative capital issuance (it can also be interpreted as an equity repurchase). So, for now, we can–rewrite the programme of a bank that operates as follows:

[1]When the Modigliani and Miller theorem does not hold the bank is indifferent between alternative capital to asset ratios, in this case our assumption is important as it pins down the value of s.

$$\max_{x\geq 0} E^{+}\left[F\left(A,x\right)+Z-\left(1-\gamma\right)\left(x+z\right)\right]-\gamma(x+z)+e$$

The model presents many cases. To grasp the intuition and illustrate the key mechanisms, it is useful to first focus on two polar situations: one where the only risks facing the bank come from legacy assets, and one where they come from prospects for new lending. Then, we will discuss the general case and, as an extension, introduce adverse selection.

2.2.2 Efficiency

As a benchmark, we define x_1 as the efficient investment level. It maximizes the economic surplus from new lending:

$$x_1 \equiv \arg\max_{x} E\left[F\left(A,x\right)-x\right].$$

This level is implicitly pinned down by the first-order condition:

$$\int_{A_L}^{A_H}\left(F_x\left(A,x_1\right)-1\right)h(A)dA=0$$

2.2.3 The risk-shifting model

Assume that new lending is risky. That is, let A follow some (non degenerate) distribution function $h(A)$ over $[A_L, A_H]$. Assume, however, that legacy asset are safe and healthy. That is, let Z be a constant with $Z\geq z$. In that case, in line with Malherbe (2016), over-lending ensues.

First, note that since we assume that $E[F_x(A,0)]>1$, the solution must be interior. The first order condition is:

$$\int_{A_0(x)}^{A_H}\left(F_x\left(A,x\right)-\left(1-\gamma\right)\right)h(A)dA-\gamma=0 \tag{4}$$

where $A_0(x)\equiv\min\{A_L,\{A\mid V(A,x)=0\}\}$ is the solvency threshold for the bank. Given x, the bank defaults if the realisation of A is below $A_0(x)$. One can rewrite the first order condition as:

$$\underbrace{\int_{A_L}^{A_H}\left(F_x\left(A,x\right)\right)h(A)dA-1}_{economic\ surplus}+\underbrace{\int_{A_L}^{A_0(x)}\left(\left(1-\gamma\right)-F_x\left(A,x\right)\right)h(A)dA}_{implicit\ subsidy}=0 \tag{5}$$

The reason why one gets over-lending then appears clearly. On top of the economic surplus, the bank enjoys an implicit subsidy. If it defaults with strictly positive probability (i.e. if $A_L < A_0(x)$), it must be that the marginal product $F_x\left(A,x\right)$ cannot cover the marginal cost of deposits $(1-\gamma)$, and the shortfall is borne by the taxpayer. This implies that, in the region $A\in[A_L, A_0(x))$,$(1-\gamma)>F_x\left(A,x\right)$. Hence, the implicit subsidy cannot be negative. Denoting x^* the bank's optimal level of lending (that solves equation 5). It must then be the case that $x^*\geq x_1$. To see this, note that the marginal surplus is zero at the point $x=x_1$ and the subsidy is positive. Hence, the bank's first order condition can only be satisfied when the bank engages in lending that generates a negative surplus.

Note also, that an increase in γ or Z decreases the implicit subsidy and makes the bank safer in equilibrium.

Proposition 1. (Over-lending) *When prospects are risky, government guarantees can lead to over-lending. In particular, if γ and Z are sufficiently small, $x^* > x_1$.*

Proof. See the Appendix. $\square$

To illustrate how γ and Z affect lending in equilibrium, we can construct the following function from condition (5)

$$\Psi(x^*, Z, \gamma) \equiv \int_{A_L}^{A_H} (F_x(A, x^*))\, h(A)dA - 1 - \int_{A_L}^{A_0(x^*,Z,\gamma)} (F_x(A, x^*) - (1-\gamma))\, h(A)dA = 0$$

When $A_0 \in (A_L, A_H)$, we have $\frac{\partial \Psi}{\partial x^*} < 0$.[2] Then, we also have

$$\frac{\partial \Psi}{\partial \gamma} = -\int_{A_L}^{A_0(x^*,Z,\gamma)} h(A)dA - \underbrace{\frac{\partial A_0(x^*, Z, \gamma)}{\partial \gamma}}_{<0} \underbrace{(F_x(A_0(x^*), x^*) - (1-\gamma))}_{<0} < 0,$$

which, keeping Z constant, implies $\frac{dx^*}{d\gamma} < 0$.[3]

Similarly, we have

$$\frac{\partial \Psi}{\partial Z} = \underbrace{\frac{\partial A_0(x^*, Z, \gamma)}{\partial Z}}_{<0} \underbrace{F_x(A_0(x^*), x^*)}_{>0} < 0,$$

which, keeping γ constant, implies $\frac{dx^*}{dZ} < 0$.

Hence, in the risk-shifting model, increases in capital requirements or improvements in the surplus from legacy assets are met by a cut in lending (which reduces the risk-shifting inefficiency). To study the intensity of such a relationships, we need to assume a functional form for $F(A, x)$ and the distribution of A, and to use numerical methods to solve the model. The left panel in figure 1 shows the relationship between x^* and γ for different levels of the expectations of A (the right panel shows the equivalent graph for the relationship between s^* and γ).

As we can see, increasing the expectation of A changes the slope of these relationships. Specifically, it means that lending becomes less sensitive to a change in capital requirements as $E(A)$ increases. Equivalently, capital becomes more sensitive. That is to say, as lending prospects improve an increase in capital requirements is met less with a cut in lending and more with an increase in capital issuance.

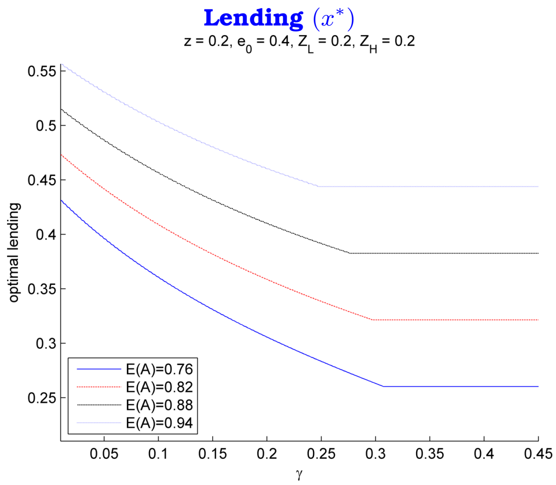
2.2.4 The legacy asset overhang model

Now, assume that new lending is riskless, that is A is a positive constant and that Z follows some non degenerate distribution $g(Z)$ over $[Z_L, Z_H]$. The first order condition for an interior solution is:

[2] Given that $F_x(A, x)$ is decreasing in x, unless $A_0 = A_H$, the left-hand-side of (4) is strictly decreasing in x, which guarantees $\frac{\partial \Psi(x^*, Z)}{\partial x^*} \neq 0$.

[3] From the implicit function theorem, $\frac{dx^*}{d\gamma} = -\frac{\partial \Psi}{\partial x^*} / \frac{\partial \Psi}{\partial \gamma}$. Since $\frac{\partial \Psi}{\partial x^*} < 0$, the sign of $\frac{dx^*}{d\gamma}$ is the same as that of $\frac{\partial \Psi}{\partial \gamma}$.

Figure 1: The Relationship Between Bank Behaviour and Capital Requirements: The Risk-Shifting Case



Notes: The figure depicts numerical solutions for the risk shifting model, under alternative marginal expected returns on lending. In this case, A is uniformly distributed and prospects follow a negative quadratic function $F(A,x) = Ax - x^2$. The return on legacy assets Z is assumed to be constant and equal to z.

$$\int_{Z_0(x)}^{Z_H} \left(F_x\left(x\right) - (1-\gamma)\right) g(Z)dZ - \gamma = 0,$$

where $Z_0(x) \equiv \min\{Z_L, (1-\gamma)\left(x+z\right) - F\left(x\right)\}$ is the solvency threshold for the bank. That is, given x, the bank defaults if the realisation of Z is below $Z_0(x)$. We can rewrite this condition as:

$$\left(F_x\left(x\right) - (1-\gamma)\right) \underbrace{\int_{Z_0(x)}^{Z_H} g(Z)dZ}_{\equiv \pi(x)} - \gamma = 0$$

Hence, the optimal level of lending x^* satisfies:

$$F_x\left(x^*\right) = \frac{\gamma}{\pi(x^*)} + 1 - \gamma \tag{6}$$

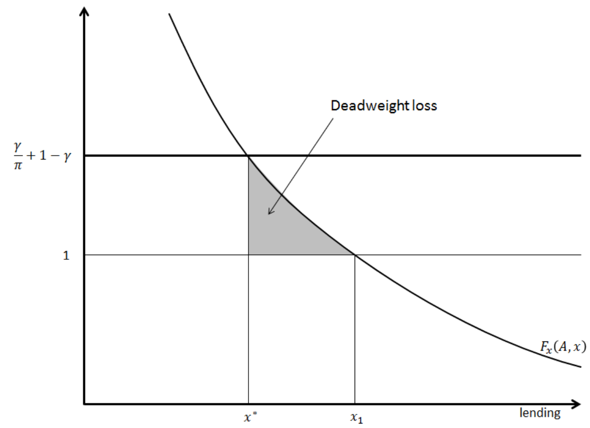
Note that $\pi(x)$ is bounded above by 1 and represents the probability that the bank will not default on deposits. Hence, the right-hand-side of (6) is bounded below by 1. This implies that $x^* \leq x_1$, which stands in contrast with the risk-shifting model.

Proposition 2. (Under-lending) *When there are potential losses from legacy assets (i.e. $Z_L < z$), they can leads to under-lending. In particular, if γ or A are sufficiently small, $x^* < x_1$.*

Proof. If $Z_0(x_1) > Z_L$, $\pi(x) < 1$. Since $Z_0(x_1)$ is weakly decreasing in γ and A, when they are large enough, we have $x^* = x_1$. But, since $A_L < A_H$, there exist sufficiently small values of γ and A such that $\pi(x_1) < 1$, which implies $x^* < x_1$. □

This is an application of the debt overhang problem in the presence of a capital requirement. One can see that by considering what the optimal x^* is for a given $\pi < 1$.

Figure 2: Illustrating the Debt Overhang Problem



Notes: This figure illustrates the overhang problem created by legacy assets. When $\pi < 1$, the relevant marginal cost of lending (i.e. the marginal cost of lending conditional on not defaulting) is strictly greater than 1. Hence, the bank passes on positive net-present-value lending opportunities.

As is typical in a debt-overhang problem, the issuance of equity (or any other junior liabilities) implies a transfer of wealth to existing creditors. This simply is because additional equity increases the buffer against losses, which increases the banks' repayment to existing creditors in case of default, without reducing it in the non-default states.

Corollary 1. (Legacy asset overhang) *A necessary condition for under-lending is:* $Z_L < (1-\gamma)\, z$.

This corollary shows that what matters is the potential downside risk of legacy assets. Note that this is not riskiness per se that matters (in the sense of the variance of the payoff) but rather the expected shortfall given default. This is because any capital issuance decreases the share of such loss that will be borne by the creditors.

From the first-order condition, with the same logic as before, we can construct:

$$\Phi(x^*, \gamma, A) \equiv \pi(x^*, \gamma, A) \left(F_x\left(A, x^*\right) - (1-\gamma)\right) - \gamma = 0$$

Since both π and F_x are increasing in A, we directly get that, keeping γ constant, $\frac{dx^*}{dA} > 0$. This is not surprising that equilibrium new lending increases when prospects improve. But note also that $\gamma\left(\frac{1}{\pi(x^*)} - 1\right)$ is the equilibrium wedge in the expected marginal cost. It is decreasing in $\pi(x^*)$ and therefore in A. This reflects the fact that greater surplus from new lending mitigates the overhang problems and reduces the inefficiency.

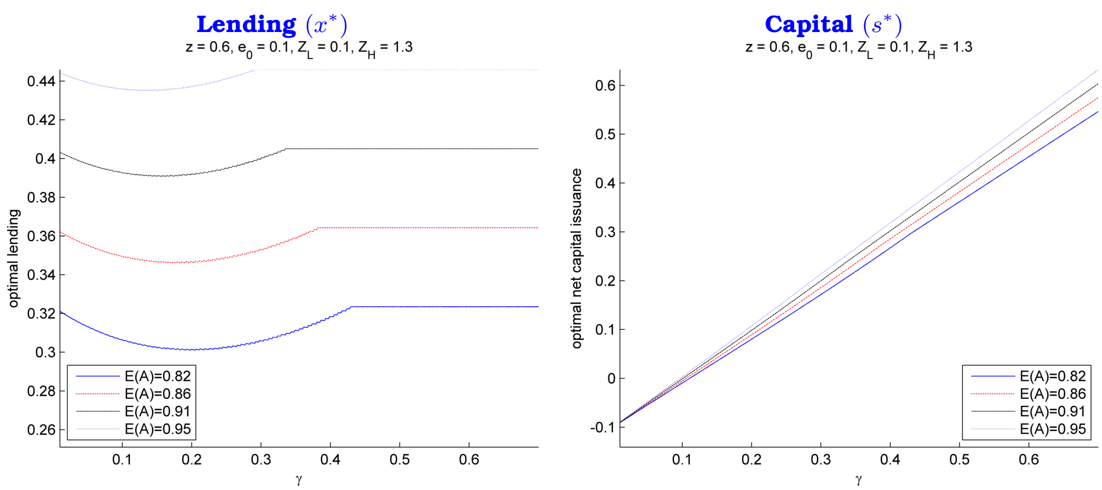
The ambiguous effect of the capital requirement Interestingly, the effect of γ is, however, ambiguous. We have:

$$\frac{\partial \Phi}{\partial \gamma} = \underbrace{\frac{\partial \pi}{\partial \gamma}\left(F_x\left(A, x^*\right) - (1-\gamma)\right)}_{>0} - \underbrace{(1-\pi(\gamma))}_{>0} \lesseqgtr 0$$

The first term captures that increasing the capital ratio increases the probability that the bank will survive ($\pi'(\gamma)$ is positive) and, therefore, capture the marginal surplus of new lending (less the cost of deposits). We call this the *recapitalisation effect:* it mitigates the debt overhang problem by reducing the probability that the bank will fail, in turn this lowers the repayment to capital when the bank survives. Hence, it reduces the relevant marginal cost of lending. The second term captures that, from the banker's point of view, capital is more expensive than deposits: while a unit of capital repays one unit in expectation, the marginal deposit is only repaid with probability π. Hence, through this channel, increasing γ increases the marginal cost of lending.

Depending on parameter values, either effect can dominate. That is, in the present case, an increase in capital requirement can either increase or decrease equilibrium lending. It is useful to use an example to illustrate this. Figure3 shows, using numerical methods, the relationship between $x^*$and γ and s^* and γ assuming that Z is uniformly distributed. There is a U-shape in the relationship between lending and the capital requirement. At relatively low values of γ, a marginal increase is met with a cut in lending. But for relatively higher initial level it is met with an increase in lending.[4]

Figure 3: The Relationship Between Bank Behaviour and Capital Requirements: The Legacy Asset Overhang Case



Notes: The figure depicts numerical solutions for the Legacy Asset Overhang model, under alternative marginal expected returns on lending. The typical U-shaped relation between capital requirement and equilibrium lending is illustrated in the left panel. In this case, Z is uniformly distributed and prospects follow a negative quadratic function $F(A, x) = Ax - x^2$. The return on legacy assets A is assumed to be a constant.

2.2.5 Taking stock

The two cases lead to different outcomes. Namely, while the riskiness of new lending points towards risk-shifting and over-lending, the legacy asset overhang points towards under-lending.

When it comes to the impact of a change in capital requirements, predictions differ as well. In the risk-shifting case, an increase in capital requirement decreases the equilibrium risk of default

[4]Such a U-shape relationship is also typical under many other distribution functions. The second derivative is: $\Phi^{''}(\gamma) = 2\pi^{'}(\gamma) + \pi''(\gamma)(F_x - (1-\gamma))$, where $\pi'(\gamma) \geq 0$. The second term is nil when Z is uniformly distributed but, in general, we have $\pi''(\gamma) = g^{'}(Z_0)(x+z)^2$, which means that one cannot rule out higher order fluctuations. However, if the probability distribution function $g(Z)$ is singled peaked, $g^{'}(Z_0)$ will typically be positive over the relevant range because default happens for relatively low realisations of Z.

of the bank. Lending can be affected (it is weakly decreasing in the requirement, which is good in terms of efficiency), but less so when lending generates a high surplus ($E(A)$ is high) and is not too risky. Indeed, if these elements are sufficiently strong the Modigliani and Miller theorem applies and changes in capital requirements have no impact on lending whatsoever.

In the debt overhang model, lending can also be affected by capital requirements. However, there are two opposite forces at play. For a given cost of capital (and probability of failure), a higher requirement contracts new lending, which decreases surplus (worsens the inefficiency) and makes the bank more risky. However, there is also the recapitalisation effect: the higher requirement also mitigates the debt overhang problem by reducing the probability of failure. Either can dominate and the model's prediction is therefore ambiguous.

2.2.6 The general case

The general case, where both new lending and legacy assets are risky, must be solved numerically. Figure 4 presents the relationship between x^* and γ for the situation where both Z and A are independently uniformly distributed and where both risk shifting and debt overhang are relevant. As we can see from the charts, the combined model also delivers ambiguous predictions regarding the slope of the relationship between capital requirements and lending (and, therefore, capital).

First of all, the ambiguity comes through the recapitalisation effect and legacy assets. Increasing the capital requirement means that the bank becomes safer, which decreases the marginal repayment to investors (in the good states, which are the only states that matter for the bank's decision). In contrast, holding the probability of default constant, then lending is always weakly decreasing in the capital requirement. Whether the effect in reality is positive or negative is an empirical question. The theory, however, can shed some light on the relative strength of these mechanisms. For the recapitalisation effect to overall dominate (i.e. for lending to increase following a tightening of the requirement), one needs (i) Legacy assets to be large with respect to the potential surplus from new lending; (ii) Their down-side risk to be sufficiently large. (iii) The initial capital requirement not to be too low.

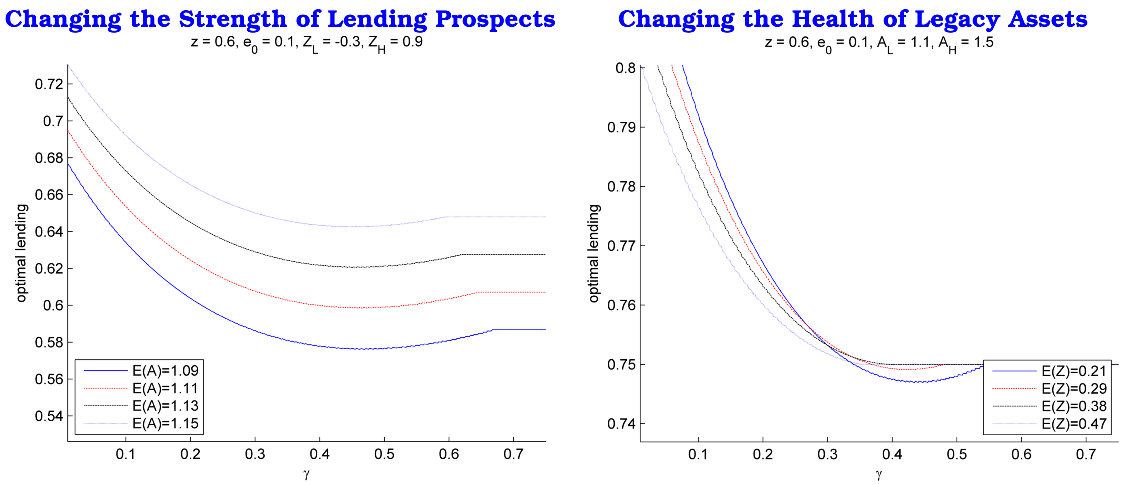
We can also say (inspecting Figure 4) that, for a given initial γ, $dx^*/d\gamma$ is increasing in $E(A)$ and $E(Z)$. *Lending will be less sensitive to a change in capital requirement when lending prospects are good and legacy assets are healthy.*

3 Empirical Strategy

The main research question of this paper is how banks react to a change in capital requirements. In a world in which the Modigliani and Miller theorem holds, lending decisions are efficient. That is $x^* = x_1$, in our model above. If the theorem holds, either the bank initially operates with a capital ratio above the requirement and small changes in the requirement are irrelevant. Or the requirement is binding and a change in requirement is met at least one for one with an increase in capital. Either way, lending is unaffected by the requirement.

As we have shown, from a theoretical point of view, different departures from the Modigliani and Miller theorem can lead to different responses. Typically, lending is affected, and the intensity of such effect (i.e. the share of the adjustment that is borne by lending rather than capital)

Figure 4: The Relationship Between Lending and Capital Requirements: The General Case



Notes: The figure depicts numerical solutions for the general case of the model, under alternative marginal ex-ante returns on lending. In this case, $A\&Z$ are independently uniformly distributed and prospects follow a negative quadratic function $F(A, x) = Ax - x^2$.

depends on the state of the economy. What we propose here is an empirical estimation of such an effect based on discretionary variations of γ for individual banks by their regulator.

Unfortunately, we cannot directly observe the distributions of A and Z for these individual banks. What we do is to proxy such variables based on the behaviour of other banks. In short, we assume that while high credit growth in the aggregate reflects good prospects (and a limited debt overhang problem), low credit growth reflects poorer prospects and/or a strong debt overhang problem.[5]

3.1 Data

3.1.1 Institutional background: the regulatory regime

To test our model's predictions, we use data from the period during which the first version of the Basel Accord was in effect in the United Kingdom (i.e. 1989Q1-2007Q4). This regulatory regime, dubbed Basel I, was relatively simple: bank capital was required to be at least 8% of risk-weighted assets (where the risk-weights corresponded to coarse time-invariant categories). The key feature, specific to the UK, is that the regulator (the Bank of England and then, from 2001, the Financial Services Authority) could impose requirements in excess of the 8% minimum in the Basel Accord. And, indeed, the regulator set higher "trigger ratios",[6] which, if breached, would trigger supervisory intervention.[7] Crucially, the regulator had discretion and could set those ratios at different levels for different banks and could also change them over time. For the purpose

[5]Note that risk-shifting does not necessarily materialise in high credit growth. Since the riskiness of new lending typically increases when prospects deteriorate, risk-shifting is likely to materialise by a smaller contraction than what would be efficient (with banks paying a high dividend).

[6]The regulatory authorities also set "target ratios" above the trigger ratio to provide a buffer to prevent accidental breaches of the trigger ratio. This practise was discontinued in 2001 but even prior to that the primary regulatory instrument was the trigger ratio.

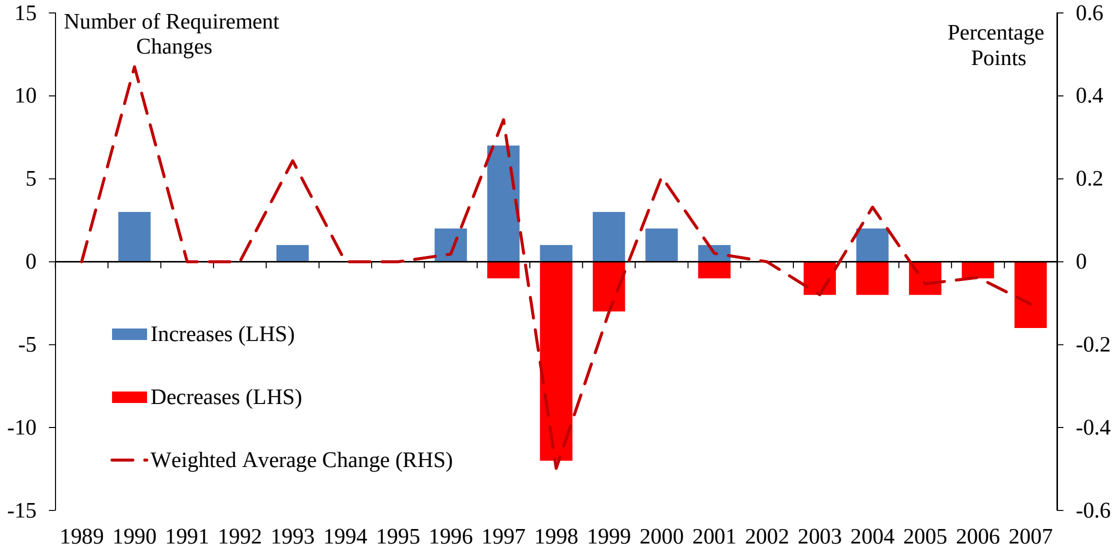
[7]Alongside increased oversight, supervisory intervention can include restrictions on dividend payouts and asset growth. In extreme cases, the regulator could shut down the institution.

Table 1: Breakdown of Capital Requirement Changes

Trigger Ratio Changes	Number	Average Absolute Size	Standard Deviation	Min	Max
Increases	22	59.3 bp	49.8 bp	7 bp	150 bp
Decreases	28	52.6 bp	34.0 bp	9 bp	129 bp
All Moves	50	55.5 bp	20.1 bp	7 bp	150 bp

Notes: Summary statistics on recorded changes in trigger ratios over the period 1989-2007 for our sample of 18 UK banks. Moves less than 5 basis points in size are set to zero.

Figure 5: Distribution of Capital Requirement Changes Through Time



Notes: The bar chart indicates the number of occasions policymakers increased (blue bar) and decreased (red bar) a capital requirement on a bank in our sample in each year. Blue line indicates the change in the average UK banking system capital requirement weighted by bank lending stocks to the non-financial private sector. Moves less than 5 basis points in size are set to zero.

of this analysis, we refer to these trigger ratios as the capital requirements. Banks were required to report their capital position and other relevant balance sheet variables in the regulatory returns that form the source of our data. Further details of this regulatory environment are described in Francis and Osborne (2009b).

Table 1 presents summary statistics for changes in trigger ratios in our sample period. Changes in the ratios were fairly evenly balanced between increases and decreases with an average move size of close to 50 basis points. Figure 5 presents the distribution of changes over time. We see a concentration of changes in capital requirements in the late 1990s but changes happened throughout the sample period and most years saw increases as well as decreases on the part of regulators.

3.1.2 Data set

We make use of the data set constructed by Bridges et al. (2014) which provides observations on a panel of UK supervised banks on a quarterly basis. Our sample period covers 1989Q1-2007Q4, when the Basel I regulatory regime was operational. The data set matches an individual bank's

Table 2: Summary Statistics

	Mean	Std dev.	25th %tile	75th %tile	Min	Max
Credit growth (%)	2.0	6.4	0.5	3.8	-46.5	45.7
of which to households	2.1	10.1	-1.0	5.6	-70.0	62.5
of which to corporates	2.5	8.2	-1.1	5.6	-41.4	46.2
RWA growth (%)	2.3	5.1	0.5	3.6	-17.7	64.6
Capital Ratio (%)	12.2	2.2	10.9	13.0	7.7	25.3
Capital Requirement (%)	9.2	0.9	8.6	10.0	8.0	11.0
Number of Included Banks:	18					
Bank Quarter Observations:	589					

Notes: Summary statistics for the data entering the state contingent local projections (all data shown at horizon $h = 0$). The data cover 18 UK banks over the period 1989-2007 under the Basel 1 regulatory regime. Credit growth in terms of lending to the non-financial private sector and is defined as flow of new lending less repayments over the existing stock (writedowns and revaluations are excluded); items may not sum as a result. RWA growth is the log change in the stock of risk weighted assets.

regulatory capital returns (i.e. filings) with the individual bank monetary returns which include detailed information on bank lending.

We use consolidated returns for the UK supervised portion of banking groups. This is a notable advantage of the data used here compared to other studies.[8] Mergers are dealt with by generating a new successor bank and discontinuing the two legacy institutions with a one quarter break in the data around the time of the merger. An alternative is to create synthetic merged institutions in the historical data, but there is then a difficulty of how to interpret a change in requirements that is only applied to one portion of the synthetic entity.[9]

Our data for lending comes from the bank monetary returns.[10] The advantage of using this data is that it is possible to determine a clean measure of the net flow of lending (new business less repayments on principal). Changes in stocks can be contaminated by other effects such as write-offs and revaluations which can lead to excessive volatility in time series data that do not reflect true lending decisions. Bridges et al. (2014) offer a detailed discussion.

We have applied a number of filtering criteria on the banks. Firstly, we have removed any banks with less than 8 quarters of regulatory or lending data as the number of observations is too low. We take the obvious step of removing any bank that breaches its trigger requirement at any point or records a negative figure for household or private non-financial corporate credit stocks. We have dropped any bank with less than £50m credit outstanding in any quarter or any which average a market share less than 0.5% of total lending. This is to prevent small volatile institutions distorting the results. This leaves us with an unbalanced panel of 18 institutions with 589 bank-quarter observations. Table 2 shows the summary statistics for the included banks using the full sample.

[8] For individual (unconsolidated) entities the availability of capital resources at the group level may distort the response to changes in requirements.

[9] The synthetic entity approach would also not allow for differing behaviour of the two entities (i.e. fixed effects) prior to the merger.

[10] Bank monetary returns are included at a unconsolidated level in the raw data but Bridges et al. (2014) aggregate the lending flows across members of the banking group.

3.2 Econometric Methodology

The local projection methodology we follow is most closely related to Jordà et al. (2013) and Jordà et al. (2015a). This specification generates non-linear impulse responses by including an interaction term with a measure capturing a contingent variable of interest, in our case a proxy for the strength of lending prospects and the health of bank balance sheets indicated by the rate of aggregate credit expansion.

To implement the local projection, we define a sequence of dependent variables over differing impulse horizons $h = \{1, 2, 3, ..., H\}$ as:

$$Y_{t+h,j} = y_{t+h,j} - y_{t-1,j}$$

Where period t is the time of the considered change in capital requirements for bank j and $y_{t,j}$ is the bank variable of interest. As we are interested in multiple aspects of bank behaviour, the definition of $y_{t+h,j}$ depends on the definition of the variable of interest. For stock items on the bank balance sheet (specifically regulatory capital and risk weighted assets) $y_{t+h,j}$ is defined as the log level such that $Y_{t+h,j}$ is the cumulative growth rate in the stock in log points from period $t-1$ to period $t+h$. For capital ratios (specifically, the capital requirement, the regulatory capital buffer and the regulatory capital ratio) $y_{t+h,j}$ is defined as a simple ratio such that $Y_{t+h,j}$ is a cumulative difference in the ratio from period $t-1$ to period $t+h$. For bank lending, we define $y_{t+h,j} = \sum_{i=0}^{h} f_{t+i,j}/S_{t-1,j}$, where $f_{t+i,j}$ is the net flow of lending by bank j in period $t+i$, purged of revaluations and writedowns (as described in section 3.1) and $S_{t-1,j}$ is the initial stock in period $t-1$. Hence, $Y_{t+h,j}$ is the cumulative net flow of lending as a percentage of the initial stock from period $t-1$ to period $t+h$.

For comparison purposes, we start by defining a linear local projection model, where the impact of a change in capital requirements is not contingent on economic circumstances:

$$Y_{t+h,j} = bank_j^h + time_{t+h}^h + \beta^h \Delta\gamma_{t,j} + \theta^h controls_{t,j} + \epsilon_{t,j}, \ldots \forall h = \{1, 2, 3, ..., H\} \quad (7)$$

Equation 7 is a sequence of H regressions for each impulse horizon h. The term $\Delta\gamma_{t,j}$ is the change in bank $j's$ capital requirement (as a ratio of risk weighted assets) at time t. The sequence of coefficient estimates $\beta^h \in \{\beta^1, \ldots, \beta^H\}$ is then used to construct impulse responses. $controls_{t,j}$ are bank specific controls. The term $bank_j^h$ is a bank fixed effect to capture differences in average growth rates across banks.[11] The term $time_{t+h}^h$ is a time fixed effect, controlling for the common response across banks to aggregate factors. To introduce non-linearities linked to aggregate credit growth, we then add interaction terms. Let X_t denote our variable to capture the rate of aggregate credit growth at the time the requirement was changed:

$$Y_{t+h,j} = bank_j^h + time_{t+h}^h + (\beta^h + \beta_x^h X_t)\Delta\gamma_{t,j} + (\theta^h + \theta_x^h X_t) controls_{t,j} + \epsilon_{t,j} \quad (8)$$

The introduction of the interaction terms in equation 8 can be interpreted as a 2nd order approximation of a generic non-linear impulse response function (Jordà (2005)).[12] The other

[11] When estimating the models for capital ratios we omit bank fixed effects as these models are already in differences and we do not think it is appropriate to allow for bank specific trend in capital ratios.

[12] Including quadratic terms in $\Delta\gamma_{t,j}$ does not alter the results and the coefficient estimates are not statistically significant hence we exclude these terms for parsimony.

variables share the same definition as above; note that no linear term on X_t is included as it is subsumed in $time^h_{t+h}$. We can then ask: how does the impact of a change in capital requirements depend on X_t? The impulse response to a unit change in the capital requirement contingent on $X_t = \bar{X}$, is defined as the sequence $\{\beta^1 + \beta^1_x \bar{X}, \ldots, \beta^H + \beta^H_x \bar{X}\}$.

We set $H = 12$. Impulse responses constructed from local projections are imprecise at long horizons (Ramey and Zubairy (2014)) and given our relatively short panel looking beyond three years leads to erratic results that are difficult to interpret. Estimation is conducted using weighted least squares, with the stock of bank lending at time t as the weighting variable. In terms of bank specific controls, $controls_{t,j}$, we included (i) the current value and lag of the bank's capital ratio; (ii) the current and lagged rate of credit growth; (iii) the lag of the capital requirement; (iv) the bank's deposit to liability ratio to proxy its liquidity position; (v) the ratio of provisions to the stock of loans and (vi) the current value and lag of $Y_{t,j}$ (if not controlled for elsewhere).

As suggested by Tenreyro and Thwaites (2015) we have conducted inference using both Driscoll and Kraay (1998) standard errors and blocked (at the bank level) bootstrapped standard errors. Both give similar results. Below we present the estimates using Driscoll and Kraay (1998) error bounds but results with bootstapped errors are available upon request.

We follow the literature (Auerbach and Gorodnichenko (2013); Tenreyro and Thwaites (2015)) in defining X_t as a backward looking 7-quarter moving average growth rate. X_t enters the regressions as credit growth less the sample mean and divided by the sample standard deviation.

There are alternative ways of introducing non-linear impulses in local projections. Auerbach and Gorodnichenko (2013) use a "Smooth Transition Local Projection" model, which assumes that the economy has two regimes. However, this requires strong priors over the function determining probability of being in each regime. Ramey and Zubairy (2014) use a binary dummy using a threshold of 6.5 in the unemployment rate, based on the Federal Reserve's focus on that value, to distinguish periods of relative economic slackness. Again there is no obvious analogue with regard to credit growth.

3.3 Identification

In the specification above, identification does not hinge on the assumption that $\Delta\gamma_{t,j}$ is orthogonal to $y_{t,j}$. If the regulator is reacting to overly strong credit growth, or other observed characteristics controlled for in the specification, when setting capital requirements, this would not pose an identification issue. That $\Delta\gamma_{t,j}$ is correlated with $controls_{t,j}$ does not bias the coefficient estimates. Changes in bank specific loan demand will also be controlled for via the inclusion of credit growth at the time of the capital requirement change in the specification.

This is an advantage of making use of local projections versus vector auto-regressions where disentangling contemporaneous relationships poses a difficulty. Furthermore, the inclusion of the term θ^h_x in equation 8 allows for any implicit differences in regulatory reaction functions at different points in the time. The consequence of this is that an estimate of the impulse at $h = 0$ cannot be obtained[13]; however, as will be shown below, the on-impact response is likely to be small anyway given lags in the Bank's ability to respond to the requirement.

Identification will break down if the regulator is reacting to factors that cannot be controlled for such as forward looking information that cannot be observed. A particular worry is that the

[13]With the exception of the response of the capital requirement to itself.

regulator is raising capital requirements in response to private information about anticipated losses. However, there are several reasons to suspect that this is not the case. First, as described in Francis and Osborne (2009b), these additional capital requirements were designed to correct for some perceived deficiencies in the Basel 1 requirement with regard to interest rate, operational, legal and reputational risks. The requirements were not set in response to credit risk. Furthermore, as described in Aiyar et al. (2014b,a), the review (Turner (2009)) into the failures of the UK regulatory regime in the wake of the global financial crisis stated that supervisors where focussed more upon organisational structures, systems and reporting procedures than bank business models when setting bank capital requirements. The inquiry into the failure of the British Bank Northern Rock noted that the regulatory framework at the time did not require the supervisors to engage in financial analysis. Lending growth and credit risk seemed from an institutional standpoint an unimportant determinant of the regulators decision over bank-specific capital requirements.

This is borne out empirically in the studies that have investigated the causality of the requirements. Aiyar et al. (2014b) show that there is little relationship between past or future loan write downs and changes in UK bank capital requirements.

Meeks (2015) goes a step further and shows that in an aggregate VAR analysis macroeconomic shocks seemed to have little impact on the average level of the capital requirement across banks.[14]

The empirical analysis below shows that banks in the medium term raised capital *ratios* at least one-to-one when the requirement was increased. This suggests that the banks themselves were unable to anticipate the move and build buffers in advance.

In light of this institutional and empirical evidence, our maintained identification assumption is that the regulator is not reacting to additional unobserved information about future path of bank lending or bank capital when setting the requirement.

4 Empirical Results

4.1 Benchmark responses to a change in capital requirement

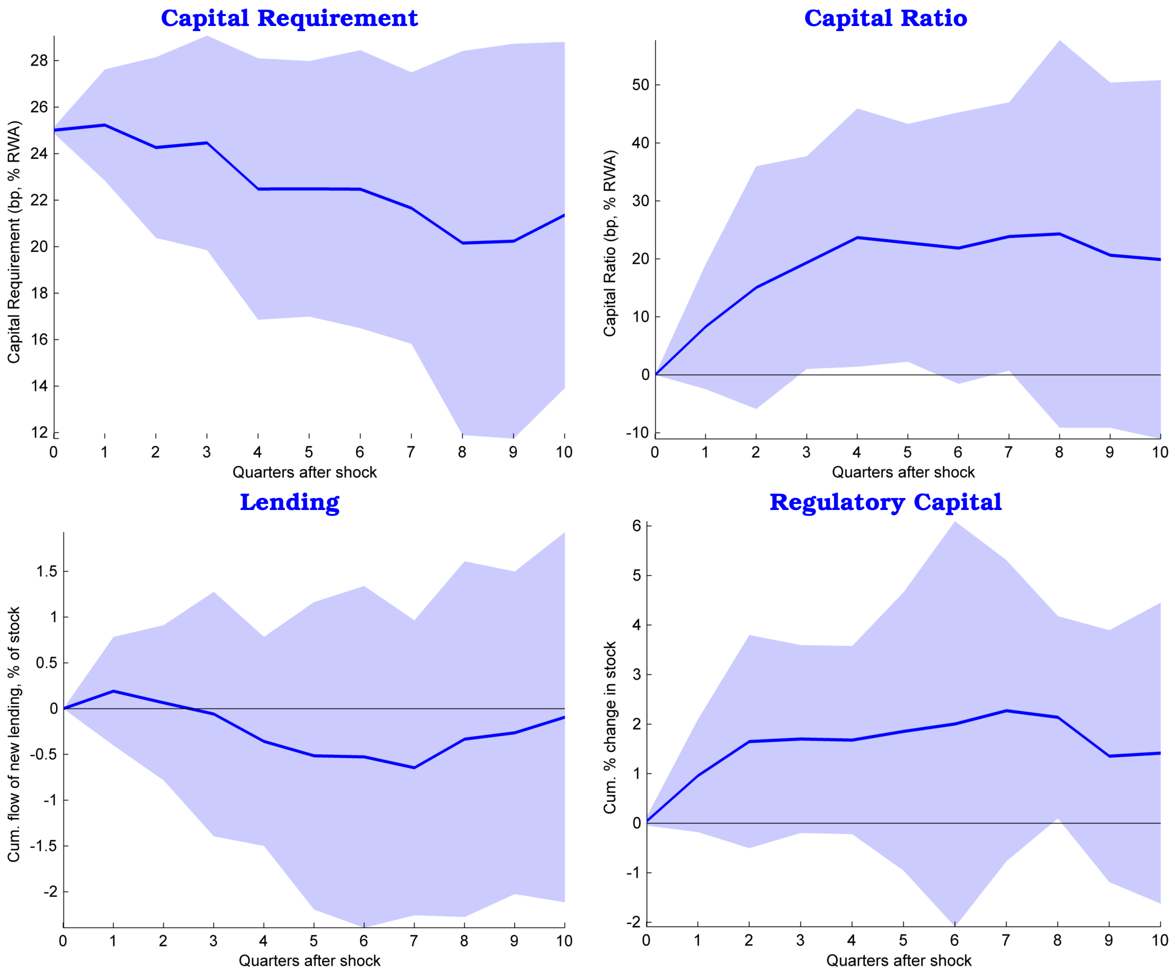
As a starting point it is informative to consider banks' unconditional responses to changes in capital requirements. Figure 6 shows our estimates for the baseline linear model (equation 7).

The upper left panel shows the estimated average path of the capital requirement following an initial increase of 25bp. Note that the point estimate suggests that the requirement decreases slightly over time. This means that, on average, the changes in capital requirements were not fully permanent: an initial increase of 25bp decays to about 20bp after eight to nine quarters. However, given the uncertainty around the estimates, we cannot reject the null of a fully persistant requirement.

The three other panels display our estimates of the banks' responses to such a change in requirements. The upper right panel shows that banks do adjust their capital ratios. The adjustment is gradual and does not reach the 25bp increase until the fourth quarter. Banks, on average, hold a voluntary buffer over and above the requirement (see table 2), which enables them to smooth the transition to a higher requirement. However, once the capital ratio reaches

[14]It is worth noting that even if regulators were systematically reacting to aggregate forces when setting bank's capital requirements those forces will be captured by $time^{h}_{t+h}$.

Figure 6: Linear Model: Response to a 25bp Capital Requirement Increase



Notes: These impulses are constructed from a panel local projection using data from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors. Linear model estimated

25bp, it stabilises around that level for the remaining horizons. We now turn to how they go about adjusting the ratio.

The lending response (lower left panel) suggests that a bank that sees its capital requirement raised by 25bp will have cut its lending by about 0.6% compared to banks that had no requirement change.[15] However, this effect is barely statistically significant at the 68% level. In contrast, the response of the level of regulatory capital is both larger (2.3% after 7 quarters, lower right panel) and statistically significant (at the 10% level at early horizons, and at the 5% level at horizon 8). In short, what we find here is that banks' adjustment mostly occurs on the capital margin.

To place numbers on this finding, we use our point estimates (namely those at the 4 quarter horizon) to compute the *ceteris paribus* change in the capital ratio they imply. To do so, we use a first order log-approximation of the implied change in the ratio assuming the bank starts from

[15]The path presented is relative both to the bank's own trend growth rate in lending (captured by the firm fixed effect) and relative to how other banks are behaving in the same time (captured by the time fixed effect).

Table 3: Contributions to the Adjustment in Capital Ratios after a 25bp Capital Requirement Increase: Linear Model

	Point estimate, response to 25bp requirement change (after 4 quarters)	Implied* change in the capital ratio
Regulatory Capital	1.7 %	20.1 bp
Lending	-0.4 %	4.3 bp
Capital Ratio	23.7 bp	~24.4 bp

Notes: *The approximation is conducted using a first order log approximation assuming banks have an initial capital ratio of 12% and that risk weighted assets grow at the same rate as lending. The response after six quarters is, empirically, the horizon where most of the adjustment in the capital ratio takes place. Point estimates are drawn from the impulse responses presented in figure 6.

an initial capital ratio of 12%. As can been seen in table 3, the change in the capital ratio implied by the response in the level of regulatory capital is close to five times larger than that implied by the cut in lending. It is worth noting that the figures in the second column of table 3 will not sum precisely to the change in the capital ratio due to approximation error and the fact banks do hold other assets than loans.[16]

The key point, however, is that these estimates only capture the average responses of banks over the sample, without taking into account the differences in economic conditions at the time they are hit by the shock. However, the results from our theoretical model is that the key determinants of how bank's respond to changes in capital requirements are the strength of lending prospects and the health of legacy assets, both of which would have varied over the sample period. The baseline results may, therefore, be misleading. For instance, if at certain points in time the impact of a change in requirements on lending is large and at others the impact is minimal then it may not be possible to obtain a statistically significant response for an unconditional average effect.

In section 3, we have argued that both these determinants can be proxied by the strength of aggregate credit expansion. In the next section, we go on to show how our results are affected when conditioning on this variable.

4.2 Banks' responses to capital requirements conditional on aggregate credit growth

To condition banks' responses to a change in capital requirements on credit growth, we generate impulse responses using the estimated parameters from equation 8. We consider how banks respond to changes in capital requirements conditional on aggregate credit growth being one standard deviation below and one standard deviation above the sample mean. The impulse responses are discussed in more detail below, but to get the point of this exercise, table 4 repeats the analysis in table 3 using the conditional impulse responses. As can be seen, in periods of credit expansion, much like the unconditional case, most of the adjustment is met through increases in the level of capital. The opposite is true when aggregate credit growth is weak, all of the increase in the capital ratio is achieved through a fall in lending. Indeed, the level capital

[16]We consider the response of total risk weighted assets in section 4.3.

Table 4: Contributions to the Adjustment in Capital Ratios after a 25bp Capital Requirement Increase: At Different Levels of Aggregate Credit Growth

Aggregate Credit Growth Above Sample Mean

	Point Estimate, response to 25bp requirement change (after 4 quarters)	Implied* change in the capital ratio
Regulatory Capital	1.2 %	14.4 bp
Lending	-0.2 %	2.0 bp
Capital Ratio	27.1 bp	~16.5 bp

Aggregate Credit Growth Below Sample Mean

	Point Estimate, response to 25bp requirement change (after 4 quarters)	Implied* change in the capital ratio
Regulatory Capital	-0.2 %	-2.0 bp
Lending	-1.6 %	19.1 bp
Capital Ratio	19.2 bp	~17.2 bp

Notes: *The approximation is conducted using a first order log approximation assuming banks have an initial capital ratio of 12% and that risk weighted assets grow at the same rate as lending. Point estimates are drawn from the impulses presented in figures 7, 8 and 9.

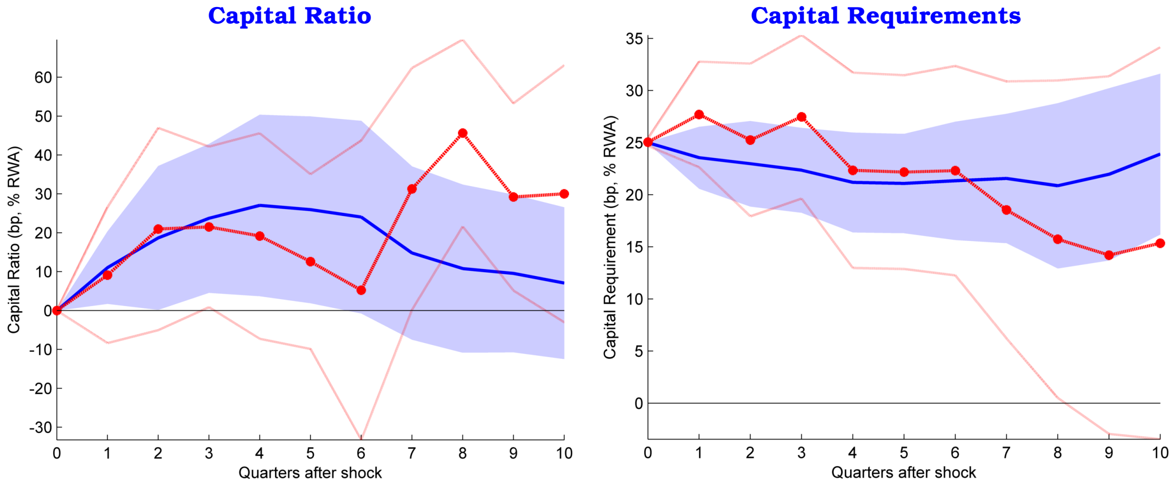
actually falls in response in an increase in the requirements. At face value, a fall in capital levels in response to a tightening of requirements may seem counter-intuitive. Using the intuition from our model, the fall in bank capital can have two explanations: (1) the fact that banks lend less in response to the change in capital requirements puts a strain on bank earnings, diminishing their equity; (2) banks choose deliberately to downsize and increase their dividend pay out rates.

Turning to the impulse responses themselves, the left panel in figure 7 shows how capital ratios respond during periods of above average credit growth (blue) and below average credit growth (red). At short horizons, less than around seven quarters, an increase in the requirement leads to a similar response in the capital ratio in both cases. However, in periods of weaker credit growth banks then after two years banks jump to a much higher capital ratio. This a strange finding with no obvious explanation; hence, we leave investigating this behaviour to future research. The responses of the requirement itself displays fairly similar behaviour across periods of strong and weak credit growth. There is a little additional propagation in weak growth times with the requirement increasing by an additional 10 basis points after one quarter but the requirements tend to decay after that, such that only around 10bp of the increase is still in place after 12 quarters.[17]

The left panel in Figure 8 shows the cumulative response of lending flows to a 25bp shock contingent on the two levels of aggregate credit growth under consideration. As can be seen, a tightening in the requirement during periods of strong credit growth has relatively limited effect; the point estimate is marginally negative and troughs at around -1%. Periods of weak credit growth, see a much stronger response: there is a statistically significant decrease in lending which troughs at about 4%. That it takes four quarters for banks to respond to a change in

[17]The equivalent estimates of β_x^h for figure 7 are in figure 11 in the appendix.

Figure 7: Conditional Response of Capital Ratios and Capital Requirements



Notes: These impulses are constructed from a panel local projection data from 18 UK banks covering 1989-2007. The shock variable is a 25bp changes in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

capital requirements, in this scenario, is a sign that these moves were unlikely to have been anticipated by the institutions and the lag in the adjustment probably reflects the time it takes for banks to adjust their behaviour. The right panel shows the estimate of β_x^h for this specification, this parameter governs the two impulses and the fact it is statistically significant (beyond the short horizon) indicates that the difference between the two impulses in the left panel is also statistically significant.

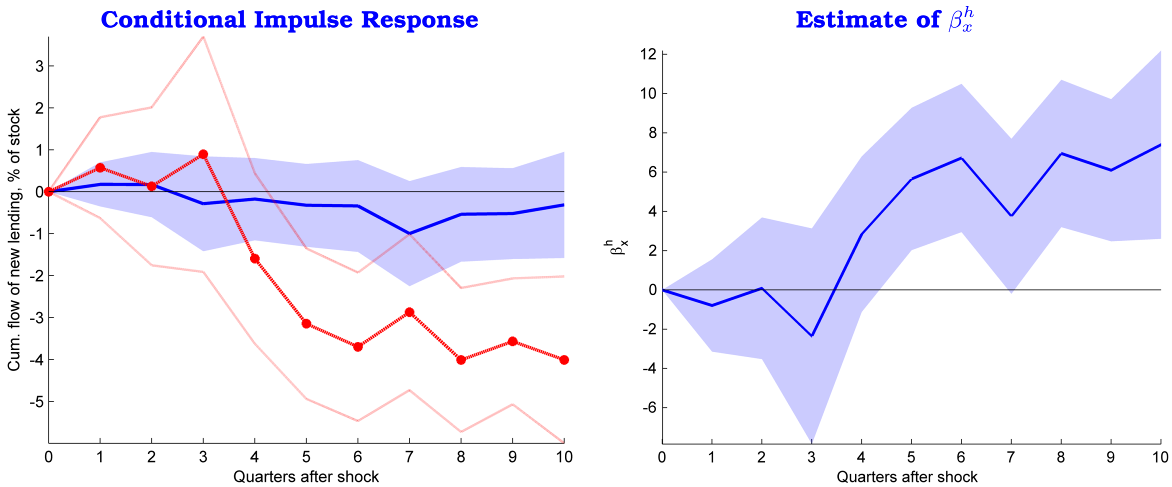
Figure 9 shows the equivalent response for the stock of bank capital. In times of above average credit growth, the level of equity rises in response to an increase in the requirement. This is consistent with the capital requirement being met via an increase in the level of capital. In contrast in weak growth periods banks capital levels actually fall by around 2-3%. However, these contrasting effects are not statistically significant, the right panel of figure 9 shows the estimate of β_x^h for the specification based on the level of bank capital.

4.3 Robustness

Ramey and Zubairy (2014) argue that it is important to consider differences between levels and growth rates when considering how to condition on aggregate conditions. For instance, a period of credit expansion may occur when the stock of credit is rising from a *low* point. As robustness check, we also define X_t using the so-called credit-to-GDP gap that the Bank of International Settlements has argued is a key indicator of the credit cycle . This variable is defined in terms of the level of credit. Figure 10 in the appendix presents the conditional impulse responses for bank lending using this specification.

Lending flows may be not representative for how banks adjust the asset side of their balance sheets in response to capital requirement changes. To test this, figure 12 of the appendix presents the equivalent conditional responses of risk weighted assets (i.e the denominator in the capital

Figure 8: Conditional Response of Lending to a 25bp Capital Requirement Increase



Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

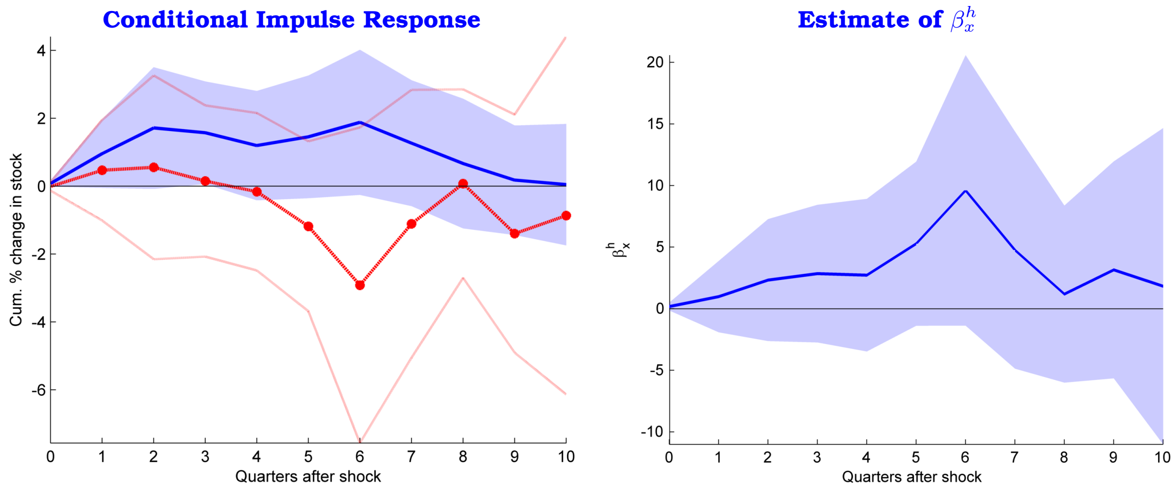
ratio) The message from these estimates is similar to those based on lending but are less precise.

We have also run the empirical analysis above with a variety of alternative specifications. For parsimony we focus on how figure 8 is affected as the specification changes, equivalent impulse responses for other figures can be obtained by contacting the authors. Figures 13 and 14 in the appendix shows the response of household and corporate lending respectively using the specification in section 4.2. Figure 16 shows the results for lending of all types when we end the sample in 2005. The years 2006 and 2007 are potentially distorted by banks adjusting to the Basel II regime that was due to come into effect in 2008. Figure 17 shows the results excluding the market share filter on banks, adding a number of smaller banks into the sample. Figure 15 shows the results including increasing the lag order of the controls to two. Last, figure 18 shows the results excluding bank fixed effects. While there are differences in terms of precision and scale across these estimates the main message from the analysis, that banks are more likely to contract lending in response to an increase in capital requirements when aggregate credit growth is weak is prevalent throughout the alternative specifications.

4.4 Discussion and extensions

To summarise our empirical findings, we find strong evidence that capital requirements are essentially binding: they directly affect a bank's capital ratio. There are periods in the data where much of the adjustment to a change in capital requirements occurs through the numerator, the level of capital. However, we find evidence to support the hypothesis that the intensity of the adjustment on the lending margin is much stronger when aggregate credit growth is low or negative. If we assume that aggregate credit proxies the strength of lending prospects. This is consistent with the risk-shifting dimension of the model. We do not find evidence of a positive adjustment

Figure 9: Conditional Response of Bank Capital to a 25bp Capital Requirement Increase



Notes: These impulses are constructed from a panel local projection data from 18 UK banks covering 1989-2007. The shock variable is a 25bp changes in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

to lending in response to an increase in requirement in any our specifications. We have tried quadratic specifications in the interaction term and also have failed to obtain a positive response. This suggests that it is unlikely that the recapitalisation effect, present in the legacy asset model, can dominate.

5 Conclusion

We propose a model to study bank capital and lending joint decisions. Potential profit and downside risk from legacy assets interact with potential profit and downside risk from new lending. In most cases the Modigliani and Miller theorem does not hold because of either a legacy asset overhang problem or the implicit subsidy from government guarantees. In that context, capital requirements affect bank decisions. The model predicts that banks react differently to changes in capital requirement depending on economic conditions. In particular, in times of weak credit growth, lending is likely to be particularly sensitive to changes in capital requirements. Using UK bank regulatory data from 1989 to 2007, we find strong empirical support for the model's predictions.

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A Proofs

Lemma. 1. *In all cases where the Modigliani-Miller theorem does not hold, the bank prefers, at the margin, to fund lending with deposits rather than capital.*

Proof. Pick an arbitrary level of lending. First, assume that, whatever its liability structure, the bank does not default if $Z = Z_L$ and $A = A_L$. Then, the Modigliani and Miller theorem applies (because when there is no risk of default, the cost of capital is the same as that of deposits). Now, assume that there are states in which the bank fails. Denote $\pi < 1$ the probability that the bank does not fail. Then, substituting a unit of deposits for a unit of capital (e.g. raising a unit of deposits and, then, paying a unit in dividend) increases shareholder's value by $1 - \pi$. This is because the dividend is received for sure, and the deposit is only repaid with probability π. □

Proposition. 1. (Over-lending) *When prospects are risky, government guarantees can lead to over-lending. In particular, if γ and Z are sufficiently small, $x^* > x_1$.*

Proof. First, note that, for all $x < x_1$, we have:

$$\int_{A_L}^{A_H} \left(F_x\left(A, x\right)\right) h(A) dA - 1 > 0 \tag{9}$$

Second, note that the definition of $A_0(x)$ implies that, for all $A \in [A_L, A_0(x)]$,

$$\left[F\left(A, x\right) + Z - \left(1 - \gamma\right)\left(x + z\right)\right] \leq 0$$

Given that $Z \geq z$, this implies:

$$\frac{F\left(A, x\right)}{x} \leq \left(1 - \gamma\right), \forall A \in [A_L, A_0(x)] \tag{10}$$

But $F\left(A, x\right)$ is concave in x. Hence,

$$F_x\left(A, x\right) \leq \frac{F\left(A, x\right)}{x},$$

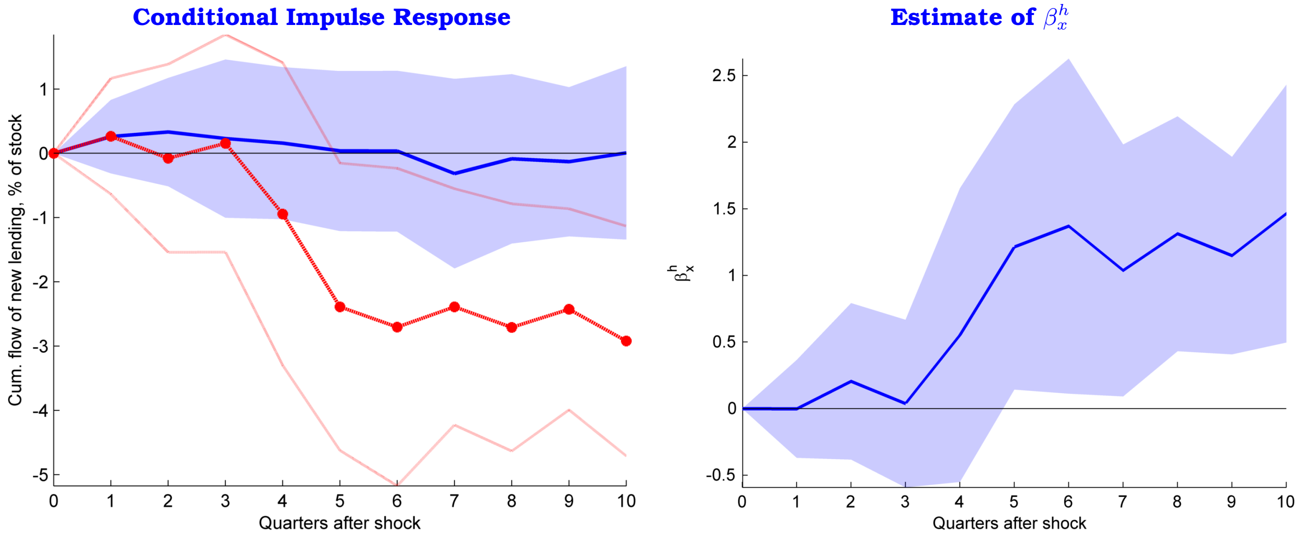
which then implies that

$$\int_{A_L}^{A_0(x)} \left(F_x\left(A, x\right) - \left(1 - \gamma\right)\right) h(A) dA \leq 0. \tag{11}$$

Together, conditions (9) and (11) imply that, for all $x < x_1$, the left-and-side of (5) is strictly positive. Denoting x^* the optimal level of lending, we then have $x^* \geq x_1$. Evaluated in x_1, the first term equals 1. There exist a $\gamma_{min} > 0$, such that for all $\gamma < \gamma_{min}$, $A_0(x_1) > A_L$ and, therefore, the second integral of (5) is strictly negative, which implies that $x^* > x_1$. □

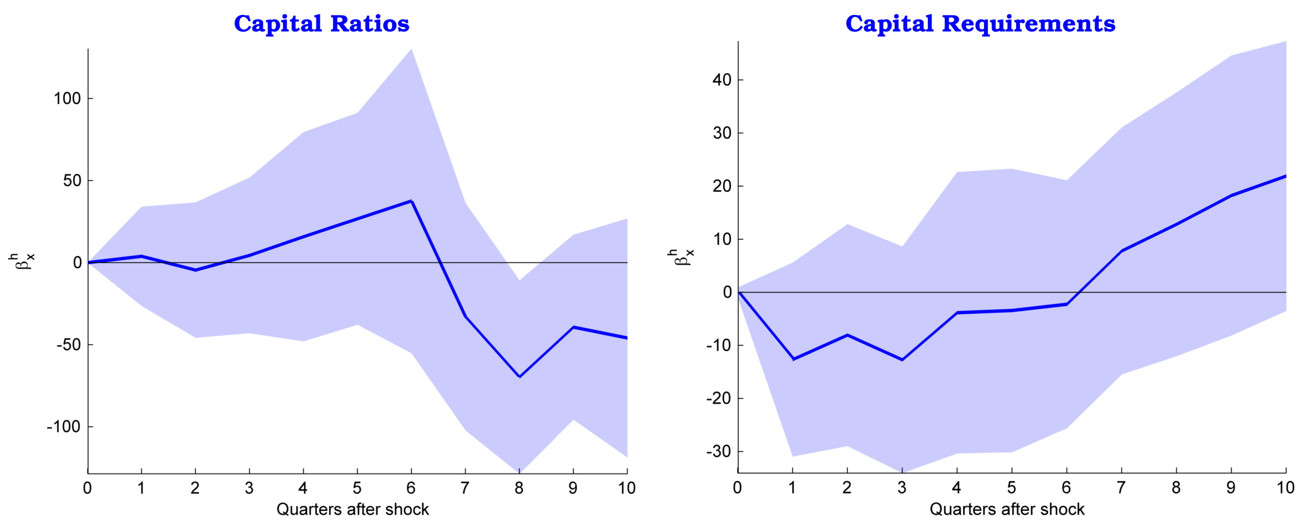
B Additional Charts

Figure 10: Conditional Response of Lending to a 25bp Capital Requirement Increase: Using the Credit to GDP Gap



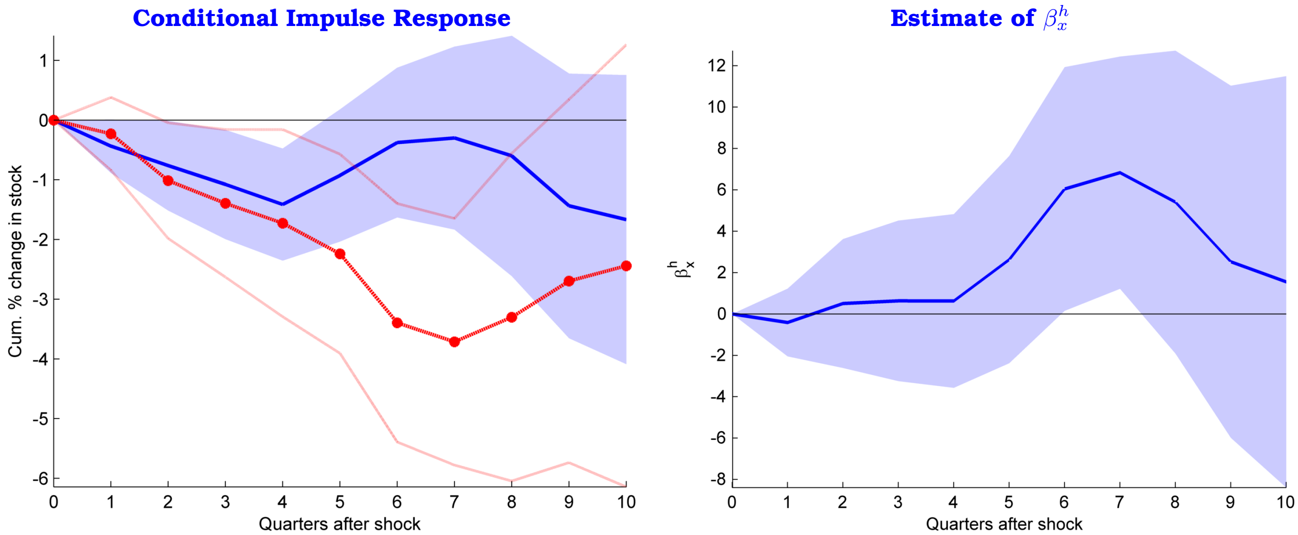
Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirement, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is credit to GDP gap 1 S.D. above and **Red Line** is aggregate credit to GDP gap 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 11: Conditional Response of Capital Ratios and Capital Requirements - estimates ofβ_x^h



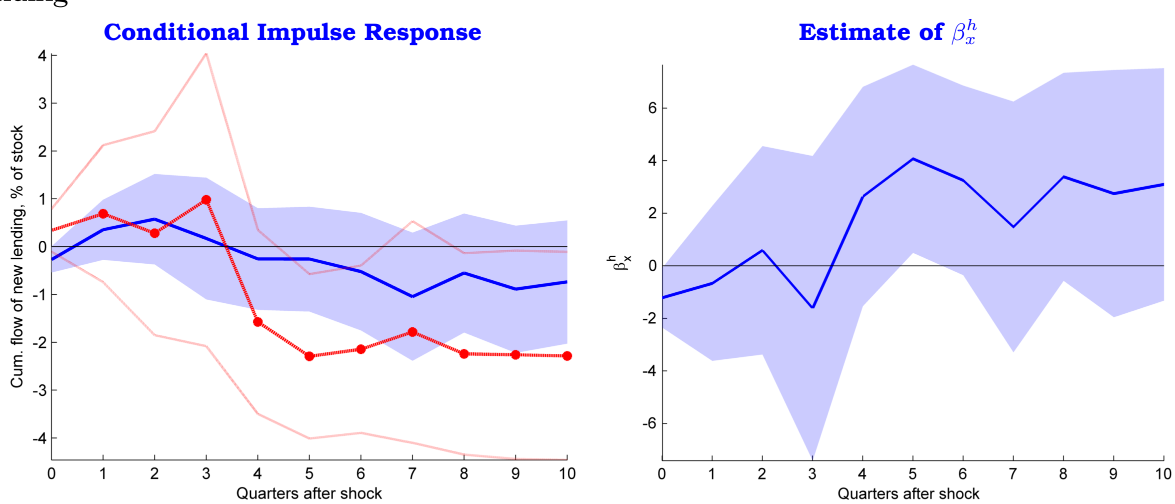
Notes: These impulses are constructed from a panel local projection data from 18 UK banks covering 1989-2007. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 12: Conditional Response of RWAs to a 25bp Capital Requirement Increase



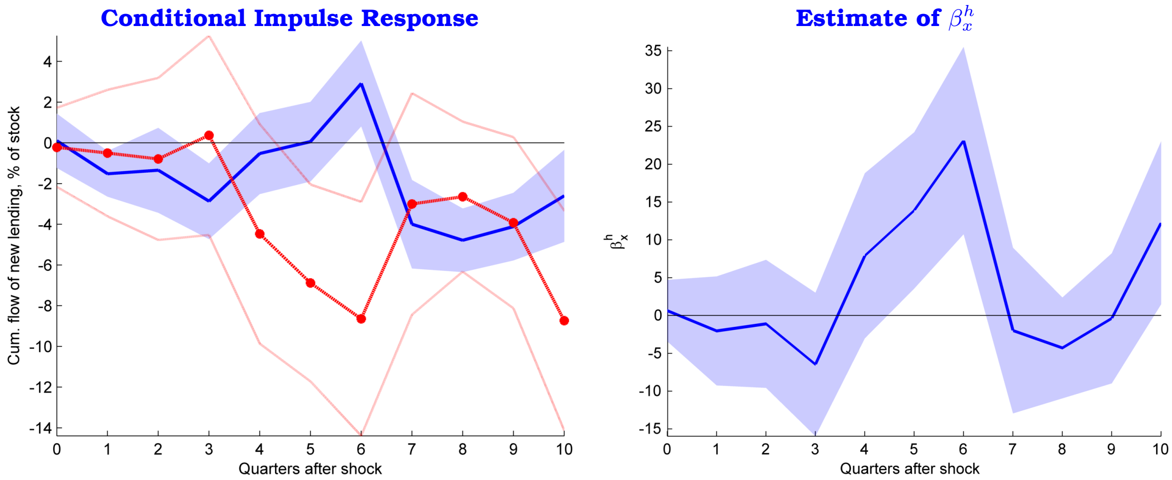
Notes: These impulses are constructed from a panel local projection data from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirement, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 13: Conditional Response of Lending to a 25bp Capital Requirement Increase: Household Lending



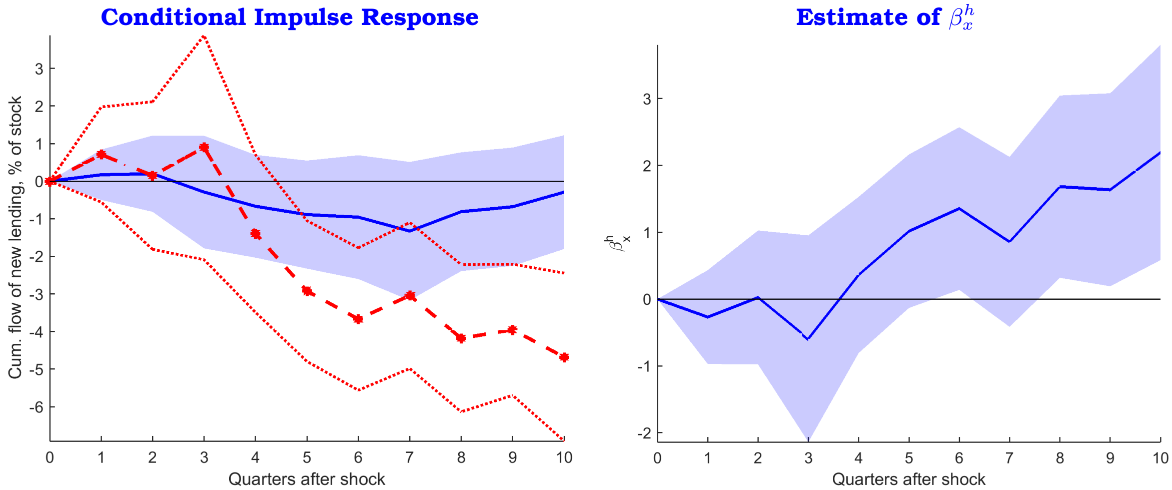
Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 14: Conditional Response of Lending to a 25bp Capital Requirement Increase: Corporate Lending



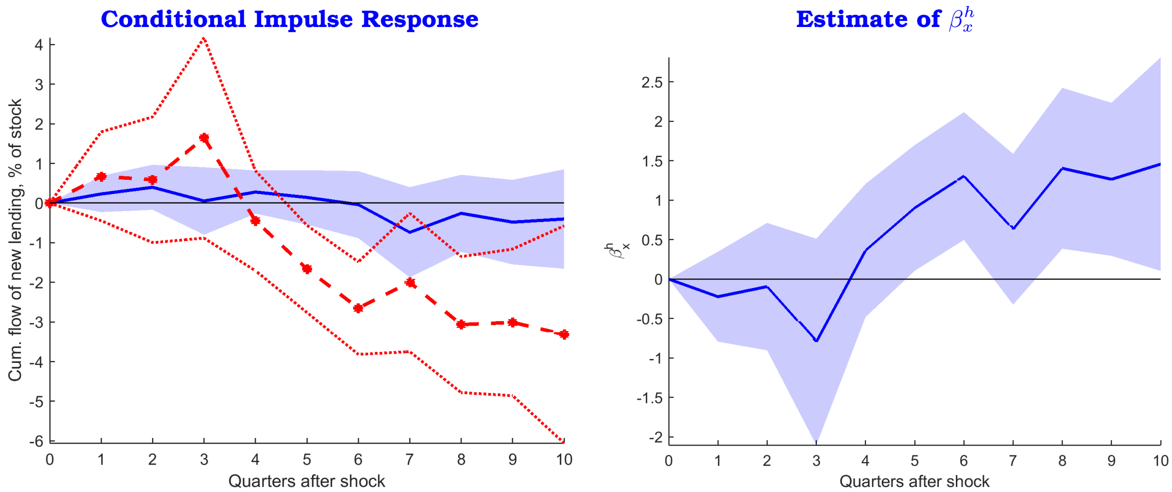
Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 15: Conditional Response of Lending to a 25bp Capital Requirement Increase: Increasing the Lag Order of the Controls to Two



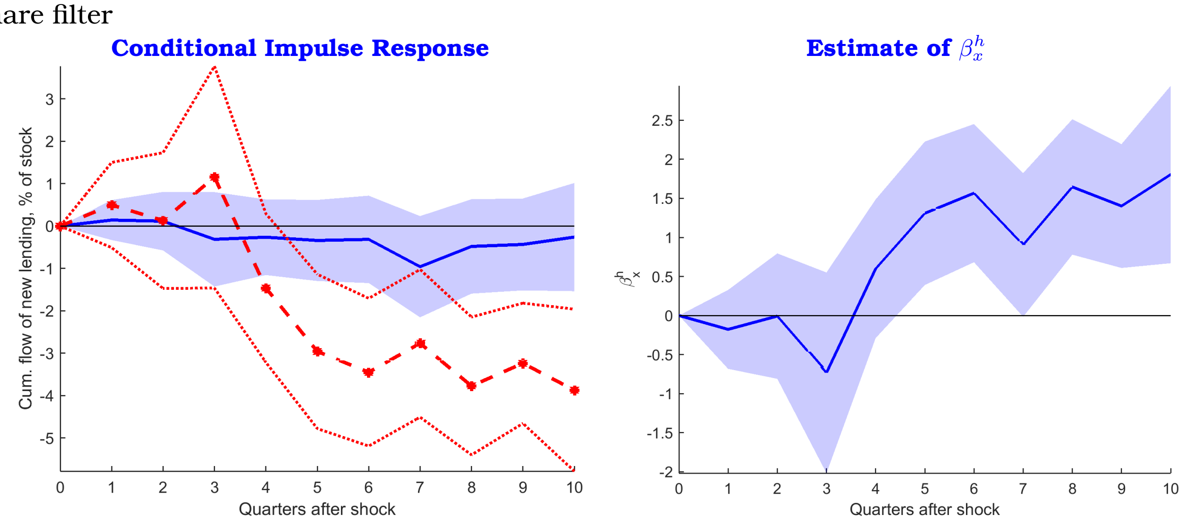
Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 16: Conditional Response of Lending to a 25bp Capital Requirement Increase: Stopping the sample in 2005Q4



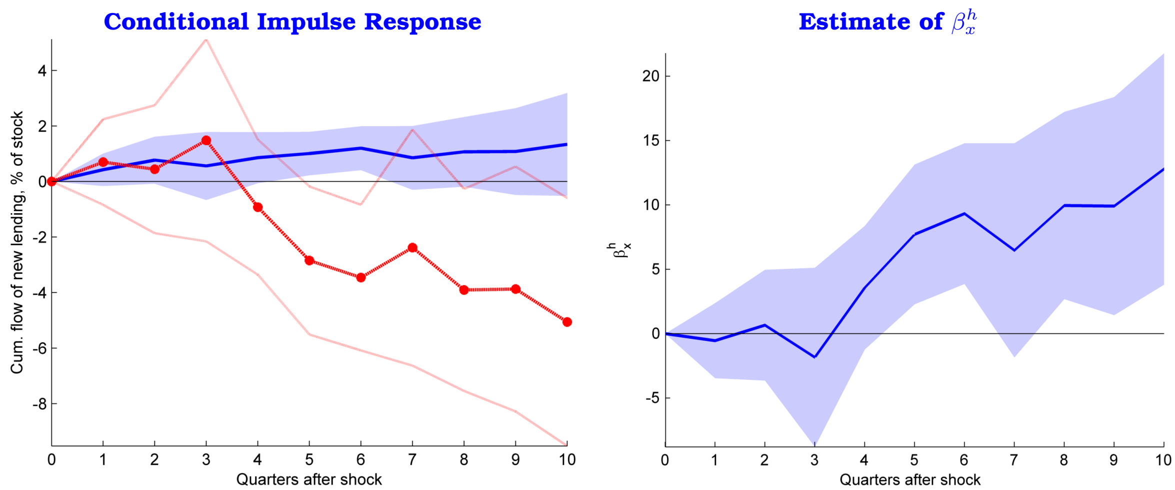
Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 17: Conditional Response of Lending to a 25bp Capital Requirement Increase: No market share filter



Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.

Figure 18: Conditional Response of Lending to a 25bp Capital Requirement Increase: No time fixed effects



Notes: These impulses are constructed from a panel local projection using lending data (household and private non-financial corporations) from 18 UK banks covering 1989-2007. The shock variable is a 25bp change in the bank's capital requirements, we interact the shock with the state of the economy to calculate differentiated impulses. **Blue line** is aggregate credit growth 1 S.D. above and **Red Line** is aggregate credit growth 1 S.D. below the sample average. Confidence intervals presented are two Driscoll and Kraay (1998) standard errors.