The Impact of Quantitative Easing and Capital Requirements on Bank Lending: an Econometric Analysis

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To my wife Shan Shan, my son Michael and my parents, Giovanni and Ameriga.

Abstract

The Impact of Quantitative Easing and Capital Requirements on Bank Lending: An Econometric Analysis

Marco Spaltro

One of the key problems of the current financial crisis is weak bank lending growth. Shortages of capital, low liquidity buffers and weak demand for bank lending have been identified as possible contributors to bank lending weakness. Given that credit booms and busts have important implications for both monetary and financial stability, policymakers acted swiftly to shore up bank lending growth by supporting demand for lending through unconventional monetary policy and by establishing a macroprudential policy framework to limit future imbalances within the financial system. While the rationales for the use of unconventional monetary policy and the establishment of a macroprudential policy framework are different, they both target, directly or indirectly, bank lending growth to achieve their objectives. The main contribution of this thesis is to estimate the impact of quantitative easing and macroprudential policy on bank lending growth by using a non-publicly available bank panel dataset of UK banks since the late 1980s. This dataset was constructed by the Bank of England by merging Bank of England balance sheet and

income statement data (including sectoral lending) with FSA regulatory returns data on capital (including bank-specific capital requirements). Differently from other research, we are able to estimate our relationships using data spanning two business cycles and to study the impact of these policies on various types of sectoral lending. We find that these new policies are non-neutral from a bank lending perspective, even though to a different extent. In particular, we find that quantitative easing in the UK has a positive impact on bank lending even though not particularly large. There is evidence that these effects may have been more important for small rather than large banks. Moreover, we also find that the effect of QE may have been smaller during the financial crisis because of lower capital ratios in the banking system. We show that changes in capital requirements (a possible macroprudential tool) affect bank capital decisions as banks try to maintain a constant buffer above capital requirements. As banks change their capital structure, bank lending growth is affected. However, there is heterogeneity in the reaction to changes in capital requirements, as large banks do not change their lending behaviour following a regulatory shock. We also provide preliminary evidence that banks respond to a regulatory shock by reducing their exposure to riskier assets in order to decrease their risk weighted assets and boost their regulatory capital ratio by reducing lending to private non-financial corporations. These findings have important policy implications. First, quantitative easing in the UK is effective in increasing bank lending growth but our simulations suggest that the amount of gilts purchased by the Bank of England may not be enough to provide a significant stimulus to bank lending growth. Moreover, these purchases may have been less effective during the crisis period because of capital constraints in the banking sector. These results suggest that larger asset purchases are needed to significantly increase bank lending and that the effect of asset purchases can be magnified by further strengthening banks' capital positions. Second, capital requirements may be an effective macroprudential policy tool and could be used by new macroprudential regulators to reduce bank lending growth in boom times in order to contain systemic risk. However, these effects may be smaller than initially envisaged as large banks seem insensitive to policy changes. There may be various reasons why these banks do not react to changes in capital requirements. For example, large banks' better access to capital markets may allow these banks to operate with smaller capital buffers. Moreover, if large banks do not react to capital requirements because of their systemic importance (e.g. because the threat of default is not credible), changes in the structure of the financial system may be necessary to enhance the impact of macroprudential policy.

Preface

I hereby declare that this thesis is the result of my own work, includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text and bibliography, is not substantially the same as any other work that I have submitted or will be submitting for a degree or diploma or other qualification at this or any other university.

I declare that Chapter 5 has been written following several discussions with Michael Joyce (Bank of England) and Chapter 6 has been written following discussions with colleagues at the Bank of England, in particular Jonathan Bridges, David Gregory, Mette Nielsen, Silvia Pezzini and Amar Radia. This thesis was completed while working at the Bank of England but the views expressed in this thesis are those of the author and not necessarily those of the Monetary Policy Committee or the Financial Policy Committee.

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Most importantly, I am grateful to my wife, Shan Shan, for her continued support through difficult times and to my son Michael, for bringing so much happiness to my family. Finally, I would have not been able to complete my studies without the teachings and counsel of my parents, Giovanni and Ameriga.

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CHAPTER 1

Introduction

One the key problems of the current financial crisis is weak bank lending growth. Shortages of capital, low liquidity buffers and weak demand for bank lending have been identified as possible contributors to bank lending weakness. Given that credit booms and busts have important implications for both monetary and financial stability, policymakers acted swiftly to shore up bank lending growth by supporting demand for lending through unconventional monetary policy and by establishing a macroprudential policy framework to limit future imbalances within the financial system. While the rationale for the use of unconventional monetary policy and the establishment of a macroprudential policy framework is different, they both target, directly or indirectly, bank lending growth to achieve their objectives.

The objective of uncoventional monetary policy is to ease monetary conditions beyond the limit posed by policy interest rates at the zero lower bound in order stimulate economic growth and reach the inflation target (Blinder (2010)). Unconventional monetary policy reaches its objectives by lowering market interest rates and by increasing the quantity of central bank money in the economy which in turn boosts asset prices, consumption and investments. At the same time, unconventional monetary policy may also support bank lending by making bank balance sheets more liquid and therefore more willing to extend new illiquid loans. Central bank asset purchases may also affect bank lending by lowering bank funding costs which may lead to higher profits, faster capital accumulation and stronger bank lending growth.

The main objective of macroprudential policy is to monitor and reduce systemic risk which is 'the risk of developments that threaten the stability of the financial system as a whole and consequently the broader economy' (Bernanke (2009)). The establishment of macroprudential regulators was necessary as microprudential regulation is on its own necessary but not sufficient to reduce systemic risk (De Nicolo' et al. (2012)). For example, UK banks were individually robust before the financial crisis and there were rare failures of financial institutions, however their high leverage and interconnectedness meant that for a given macroeconomic shock the loss to the financial system was significant (Bank of England (2009)). Therefore, macroprudential policy may reach its objectives of reducing systemic risk by cooling credit growth when large swings in credit pose risks to financial stability. For example during a credit boom, the macroprudential regulator may decide to increase capital requirements to reduce credit growth.

Although we can identify objectives and possible transmission mechanisms, estimating the effects of these policies on bank lending is a challenging task. This is mainly because these policies are unprecedented and there is no widely accepted empirical framework to analyse their impact on bank lending. Moreover, given their rare occurrence, there is a limited availability of data. For these reasons highlighted above, the empirical literature is still developing.

Recent empirical literature on unconventional monetary policy focuses mainly on the effect of these policies on financial markets and the broader economy (e.g. Joyce et al. (2011), Gagnon et al. (2010)). This research finds that unconventional monetary policy is effective in lowering financial market yields, boosting economic growth and supporting bank lending growth. But to our knowledge little has been done to estimate the impact of unconventional monetary policy on bank lending using panel data (an exception is Bowman et al. (2011)) and there is currently no research on the impact of quantitative easing on UK banks.

The literature on the impact of capital requirements on bank lending generally finds that changes in capital requirements affect bank capital ratios, lower bank lending growth and increase bank lending spreads (e.g. Francis and Osborne (2010), Osborne et al. (2012), Aiyar et al. (2012)). These studies therefore provide some evidence that macroprudential policy may be effective in containing excessive credit creation. However, this research does not provide an insight on whether the impact of capital requirements varies with banks' characteristics and if banks respond by changing the composition of the loan portfolio.

The main contribution of this thesis is to estimate the impact of quantitative easing and macroprudential policy on bank lending growth by using a non-publicly available bank panel dataset of UK banks since the late 1980s. This dataset was constructed by the Bank of England by merging Bank of England balance sheet and income statement data (including sectoral lending) with FSA regulatory returns data on capital (including capital requirements). Differently from other research, we are able to estimate the main regressions using data spanning over two business cycles and study the impact of these policies on various types of lending. We find that these policies are non-neutral from a bank lending perspective, even though to a different extent.

In particular, we find that quantitative easing in the UK has a positive impact on bank lending even though not particularly large. There is evidence that these effects may have been more important for small rather than large banks. Moreover, we also find that the effect of QE may have been smaller during the financial crisis because of lower capital ratios in the banking system.

We show that changes in capital requirements (a possible macroprudential tool) affect bank capital decisions as banks try to maintain a constant buffer above capital requirements. As banks change their capital structure, bank lending growth is affected. However, there is heterogeneity in the reaction to changes in capital requirements, as large banks do not change their lending behaviour following a regulatory shock. We also provide preliminary evidence that banks respond to a regulatory shock by reducing their exposure to riskier assets in order to decrease their risk weighted assets and boost their regulatory capital ratio by reducing lending to private non-financial corporations.

These findings have important policy implications. First, quantitative easing in the UK is effective in increasing bank lending growth but our simulations suggest that the amount of gilts purchased by the Bank of England may not be enough to provide a significant stimulus to bank lending growth. Moreover, these purchases may have been less effective during the crisis period because of capital constraints in the banking sector. These results suggest that larger asset purchases are needed to significantly increase bank lending and that the effect of asset purchases can be magnified by further strengthening banks' capital positions.

Second, capital requirements may be an effective macroprudential policy tool and could be used by new macroprudential regulators to reduce bank lending growth in boom times in order to contain systemic risk. However, these effects may be smaller than initially envisaged as large banks seem not to react to policy changes.

This thesis is structured as a consistent piece of research on the impact of unconventional monetary policy and macroprudential policy. In Chapter 2 we review the literature on the impact of (conventional and unconventional) monetary policy and capital requirements on bank lending. Chapter 3 sets the scene for the empirical papers by describing the transmission mechanism of QE and capital requirements in the UK. In Chapter 4 we present two simple theoretical models that derive priors on the effects of Quantitative Easing and capital requirements on bank lending. In Chapter 5 we estimate the effect of QE on bank lending and then simulate the effect of QE using actual Bank of England's asset purchases. Chapter 6 estimates the impact of changes in capital requirements on bank lending in the UK. Chapter 7 concludes.

In the following paragraphs we summarise the thesis in more detail. In Chapter 2 we review the most relevant literature on the transmission mechanism of conventional and unconventional monetary policy and capital requirements on bank lending. In the first section we look at the findings of the bank lending channel literature which establishes a role for banks in the transmission mechanism of monetary policy (e.g. Kashyap and Stein (1994), Kashyap and Stein (2000)). We then turn to the role of bank capital in the transmission mechanism of monetary policy to show that monetary policy is more effective in a financial system with more robust financial institutions (e.g. Van den Heuvel (2002), Jimenez et al. (2010)).

After analysing the literature on conventional monetary policy we look at current research on unconventional monetary policy which focuses on the effects of unconventional policy on financial markets and the broader economy (e.g. Joyce et al. (2011), Gagnon et al. (2010)). To our knowledge little has been done to estimate the impact of unconventional monetary policy on bank lending (Bowman et al. (2011) is an exception) and there is currently no research on the impact of quantitative easing on UK banks.

In the second section we review the literature on the relationship between capital and lending. While this research generally finds that capital matters for bank lending (e.g. Bernanke and Lown (1991) and Peek and Rosengren (1997)) they do not answer the question on whether capital *requirements* affect bank capital and bank lending. This is because changes in capital requirements are a rare event, for example the introduction of Basel I accord in 1988, and it is difficult to obtain robust estimates.

However, UK studies exploit the fact that the Bank of England and the FSA have set time-varying individual capital requirements for more than three decades, so called 'trigger' capital ratios (capital requirements from now on). These additional requirements were set by UK regulators starting in 1989 as the regulators felt that Basel I Accord did not take into account a wide range of risks (e.g. interest rate risks, reputational and operational risks) that may affect firms' probability of default (Richardson and Stephenson, 2000). Capital requirements are usually set above the minimum regulatory capital and are mainly based on general market conditions, risk management practice and strength of individual banks' controls (FSA (2001), Francis and Osborne (2009)). If a bank breaches this 'trigger' level, regulatory action is taken. The capital requirements are set by the FSA on a bank by bank basis and vary over time (they are usually reviewed every 18-36 months) which allows us to use it as a proxy for a macroprudential instrument.

The literature using UK data on bank specific capital requirements, e.g. Ediz et al. (1998), Alfon et al. (2005), Francis and Osborne (2009) find that banks change their capital ratios following a regulatory changes in capital requirements, i.e. capital requirements are binding.

Moreover, Francis and Osborne (2010), Osborne et al. (2012) and Ayiar et al. (2012) show that changes in capital requirements lead to a reduction in bank lending volume and an increase in bank lending spreads. These findings, along with the effect of capital requirements on capital ratios, suggest that capital requirements may be an effective macroprudential tool.

Chapter 3 sets the scene for the empirical analysis. We first define unconventional monetary policy and macroprudential policy and suggest that these new policies were necessary to restore financial and monetary stability after the financial crisis. We briefly describe the UK financial system before and after the crisis, focussing in particular on bank lending. We show that the boom in bank lending was funded mainly by an increase in leverage which increased financial fragility and then led to a sharp contraction in credit. From the description of the fragilities of the UK financial system we turn to the transmission mechanism of unconventional monetary policy (Quantitative Easing, QE) and macroprudential policy (focussing on capital requirements) on bank lending in the UK.

QE can affect bank lending indirectly, by boosting demand, and directly by changing the composition of banks' balance sheets. QE affects banks' balance sheets because the Bank of England purchases assets from non-bank financial institutions which leads to an increase in banks' deposits and reserves held at the Bank of England. These additional reserves mean that banks' holdings of liquid assets will have increased, making them less reliant on seeking wholesale funding to manage their liquidity needs. Put another way, the extra deposits that banks consequently held will have helped relieve any funding constraints they may have faced. Since these constraints are more likely to bind in times of financial stress, it seems possible that this might have led to additional lending.

After looking at QE, we then analyse the transmission mechanism of macroprudential policy by focusing on changes in capital requirements. When the macroprudential regulator increases capital requirements during a credit boom banks have three options to meet the new requirements: a) reduce bank lending, b) reduce the riskiness of their exposures and c) issue fresh equity. However, issuing new equity can be costly because of asymmetric information (Myers and Majluf (1984)), debt overhang problems (Myers (1977)) and because of deductibility of debt interest payments. Therefore banks are likely to respond to an increase in capital requirements by cutting lending and/or by reducing asset side riskiness.

As discussed previously, the existence of the transmission mechanism of QE and capital requirements hinges on the presence of imperfections in the debt and equity markets. In Chapter 4 we therefore develop a theoretical framework based on Kashyap and Stein (1994) adverse selection model to derive priors on the effects of QE and changes in capital requirements on bank lending.

Kashyap and Stein (1994) present a simple partial equilibrium model with a stylised bank balance sheet and shocks to deposits that are driven by changes in monetary policy stance (e.g. a change in interest rates). Following these shocks the bank may decide to issue non-deposit liabilities if the stock of liquid assets is not enough to absorb the reduction in deposits. Loans cannot be liquidated so only securities can be drawn down following shocks to deposits. The key feature of this model is that, because of adverse selection, issuing non-deposit liabilities is costly so that a shock to deposits (e.g. because of QE) leads to a change in bank lending, the so called 'bank lending channel'. Moreover, the standard model also predicts that there is a different reaction of large and small banks as their costs of issuing non-deposit liabilities vary. After examining the effects of QE on bank lending using this stylised model, we develop a simple new model where we include a shock to capital and capital requirements to derive the bank lending supply equation.

These simple models give us two testable predictions on the effects of QE and capital requirements on bank lending supply. First, the model predicts that an increase in deposits following QE leads to an increase in lending. And the effect of changes in deposits is stronger for small banks than for large banks because small banks find issuing non-deposit liabilities more costly. Second, changes in capital requirements have an effect on bank lending. Therefore, increases in capital requirements may be a useful tool to contain excessive credit creation. On the other hand, the model also suggests that these effects are heterogenous across banks. Large banks react less to changes in capital requirements than small banks because of lower costs of issuing capital.

Chapter 5 tests for the existence of the bank lending channel and quantifies the effect of the Bank of England's QE policy during 2009-10 on bank lending using a new non-publicly available panel dataset on UK banks. To our knowledge this is the first paper that attempts to estimate the effect of the Bank of England programme of asset purchases on bank lending.

The use of this unique dataset allows us to model the relationship between bank lending growth and its determinants over a twenty-year period pre-dating the financial crisis and to explore whether the relationship between deposits and bank lending changed during the crisis. We find that the bank lending channel exists and that Bank of England's QE programme had a positive, albeit economically small, effect on bank lending.

Another important finding is that the estimated positive effects of unconventional monetary policy on bank lending may have been smaller during the crisis given sharp reductions in capital ratios by major UK financial institutions. Along with other studies (e.g. Van den Heuvel (2002), Jimenez et al. (2010)) these findings suggest that there is a tight relationship between the effectiveness of monetary policy and bank capital. We also explore heterogeneities between large and small banks and find that the effect is mainly driven by small banks. This is intuitive given that small banks may find more costly to issue non-deposit liabilities during the financial crisis and therefore may be more credit constrained than large banks.

Finally, using the historical relationships between bank lending growth and deposit growth, macroeconomic indicators and individual controls, we simulate the effects of the actual asset purchases on the banking sector. The simulations suggest that the economic impact is small and that more asset purchases would be necessary to generate a significant increase in bank lending.

In Chapter 6 we estimate a dynamic model of bank lending growth to quantify both short and long-run effects of changes in capital requirements on bank lending growth. We also estimate a capital equation to understand how changes in capital requirements are transmitted to banks' capital ratios. To do so we employ a newly constructed and non-publicly available dataset with data since 1989 encompassing two full business cycles.

The effect of the increase in capital requirements is transmitted through increases of actual holdings of capital. Capital requirements are therefore binding, a necessary conditions for the transmission mechanism to work.

As capital requirements affect the composition of banks' liability side, we would expect to have an effect on bank lending too. Our results suggest that the effect of capital requirements on lending is quite large and highly statistically significant. But the effect is not homogenous and large and small banks react differently to an increase in capital requirements. In particular, large banks seem insensitive to a change in regulatory policy, while small banks react to it quite strongly. This could have potentially important implications as few large banks constitute a conspicuous slice of the lending market. We also find that banks not only reduce the volume of lending but de-risk their balance sheet in the short term by cutting lending to private non-financial corporations in an effort to reduce their risk weighted assets.

From a policy perspective, the macroprudential authority should therefore take into account that changes in capital requirements are likely to affect bank capital ratios, the volume and composition of lending. But the effects on total lending may be lower than initially estimated as large banks may not be affected by changes in capital requirements. If large banks do not react to capital requirements because of their systemic importance, changes in the structure of the financial system may be necessary to enhance the impact of macroprudential policy.

CHAPTER 2

Literature review

2.1. Introduction

In this non exhaustive literature review we consider relevant research that will provide a useful background for the following theoretical and empirical chapters. In the first section we review the main papers on the relationship between monetary policy (both conventional and unconventional) and bank lending from a partial equilibrium perspective. The theoretical and empirical backing for the existence of this channel is the so called 'bank lending view' according to which monetary policy affects bank lending not only by changing the demand for lending, but also by affecting the supply of bank lending. This theory hinges on economic frictions in debt markets and the imperfect substitutability of bank lending and bonds by corporates. Overall, existing evidence seems to suggest that conventional and unconventional monetary policy have an effect on bank lending supply even though the analysis, especially for unconventional monetary policy, is still largely unexplored.

In the second section we consider the literature on the effects of capital and capital requirements on bank lending. Similarly to the bank lending view, changes in capital and capital requirements have the potential to affect bank lending because of frictions in the market for equity. While empirical evidence on the relationship between capital and bank lending is particularly developed, literature on the impact of capital requirements on bank lending is more limited. This is because changes in capital requirements are rare and often affected several banks at the same time making the estimation process difficult for empirical economists. However, the UK provides a useful natural experiment because regulators have been setting bank by bank capital requirements for over two decades, the so called 'trigger capital requirements'. Several papers use this natural experiment to estimate the effect of capital requirements on banks' capital and lending decisions and generally find that changes in capital requirements affect banks' behaviour.

2.2. Evidence on the effects of conventional and unconventional monetary policy on bank lending

The literature on the impact of recent 'unconventional' monetary policy (e.g. QE, Troubled Asset Relief Programme and Securities Markets Programme (SMP)) on bank lending is still developing. However, the effects of standard monetary policy, where the main tool is a changes in interest rates or reserves, on bank lending have been widely examined in the theoretical and empirical literature. For example, the bank lending view suggests that because of the existence of frictions in debt markets and non perfect substitutability of bonds and bank lending, changes in monetary policy affect bank lending and the real economy over and above its effect on demand. In other words, the bank lending view gives banks an important role in the transmission mechanism of monetary policy. The existence of this channel has been debated for many years, but the development of panel econometric techniques and the use of bank and firm level data produced more evidence in favour of the bank lending channel.

If standard monetary policy is likely to affect bank lending, unconventional monetary policy may affect bank behaviour too. For example, Quantitative Easing (QE) in the UK impact banks balance sheet by increasing banks' deposit base and reserves and by lowering their funding costs. While evidence on this particular channel is limited at the moment, initial empirical evidence in other countries seems to confirm that this channel may exist.

In the sections below we start by reviewing existing research on the bank lending view and we then review recent empirical papers on the impact of unconventional monetary policy on the broader economy and bank lending.

2.2.1. Effects of standard monetary policy on bank lending

In the classic *money view* of the monetary policy transmission mechanism, banks cannot affect the real economy as they do not do anything 'special' compared to other agents (e.g. households): they hold only two assets, money and bonds. In this stylised world, changes in monetary policy affect the real economy only because of frictions in the price adjustment process (Kashyap and Stein (1993)). A monetary policy tightening reduces banks' deposits and this reduction leads to a contraction in bonds held by banks. The household sector will therefore hold less money and more bonds on the asset side of their balance sheet. With a sticky adjustment in prices, the reduction in household money balances reduces real money holdings and leads to higher real interest rates which lowers investments and real economic growth. In this simplified framework, banks do not have a separate role in accentuating the decline in economic activity and changes to banks' liabilities do not affect banks' profitability and lending. In other words, the Modigliani-Miller theorem holds in this world.

For example, Romer and Romer (1990) argue that, following a monetary tightening and a subsequent decline in deposits, banks can always frictionlessly issue non-deposit liabilities to make up the shortfall in deposits. In this case, the change in monetary policy affects the real economy only through a decline in loan demand (i.e. an inward shift of the loan demand curve) and will have no independent impact on banks' lending, i.e. an inward shift of the loan supply curve.

In contrast to the money view of the transmission of monetary policy, the *bank lending view* establishes a specific role for banks (Bernanke and Blinder (1989)). In this theoretical framework, banks not only hold money and bonds, but can also extend loans. If the change in reserves has an independent impact on bank lending and if some firms are dependent on bank loans because they cannot access the bond market, changes in monetary policy will have an impact on economic activity through an inward shift of the lending supply curve which will not be captured only by increases in real interest rates.

Kashyap and Stein (1993) adopt the Bernanke and Blinder (1988) definition of the bank lending channel and investigate whether the various conditions for which the bank lending channel exists are empirically satisfied. According to this research, there are three necessary conditions for the lending channel of monetary policy transmission to exist: a) bonds and bank loans must not be perfect substitutes for firms on the liability side of their balance sheet, b) the central bank, by changing the amount of reserves in the banking system must be able to affect the supply of loans and c) there exists some sort of imperfect adjustment that prevents any monetary tightening from being neutral. After reviewing the existing empirical literature, Kashyap and Stein conclude that the evidence on the *existence* of the bank lending channel is quite strong, even though more evidence would be needed to quantify the impact of the bank lending channel on the real economy.

Bernanke and Blinder (1992) is probably the first comprehensive study to provide empirical evidence on the existence of the bank lending channel. The authors use time series data to first show that a monetary tightening reduces bank deposits and also banks' holdings of securities, while the change in monetary policy affects bank lending only with a lag. However, these conclusions can also be interpreted as supporting the money view because monetary policy tightening may affect lending via a reduction in loan demand. Kashyap et al. (1993) try to solve this identification problem by examining demand for corporate external financing during periods of monetary tightening. They find that following increases in interest rates, commercial paper issuance increased even when bank lending declines markedly and they interpret this result as evidence of a shift in the bank lending supply curve while demand for financing remained strong.

However, other authors (e.g. Oliner and Rudebush (1993)) argue that these results are also consistent with the fact that monetary policy affect small firms more than large firms rather than a genuine shift in loan supply. In this case, bank lending declines because small firms' demand contracts, while large firms that are less affected by tighter monetary policy will continue to issue corporate paper.

In an attempt to understand better these sectoral differences and the implications for the bank lending channel, Kashyap and Stein (1994) develop a simple adverse selection theoretical model to formulate predictions consistent with the bank lending view and then use disaggregated data on US banks to test their model's predictions. They find that small and large banks react differently to a change in monetary policy, with small banks being more affected than large banks because the former are more affected by capital markets frictions. The authors argue that these results are consistent with the bank lending view even though the limited length of the time series does not allow them to obtain conclusive results. In line with Kashyap and Stein conclusions, Kishan and Opiela (2000) find that small banks are significantly impacted by changes in monetary policy.

Ashcraft (2006) conclusions are in line with the existence of the bank lending channel as he shows that large banks react less to a monetary policy shock because these banks can issue more easily non-deposit liabilities to offset the policy induced decline in deposits. However, the author uses then a structural VAR to conclude that the effect of the bank lending channel on the real economy is limited. Khwaja and Mian (2008) use a loan level bank panel dataset and unexpected nuclear experiment in Pakistan, accompanied by government prohibition to US dollar payments, to analyse the effects of liquidity shocks on bank lending. The authors find evidence of a sizeable bank lending channel and find that large and politically connected borrowing firms are more able to substitute away the credit crunch.

Kashyap and Stein (2000) provide strong empirical evidence on the existence of the bank lending channel using a large panel dataset of US banks by showing that within the small banks category those with a smaller liquid asset buffer react to a tightening in monetary policy more sharply than those with a larger buffer. This is because small banks with a small buffer of liquid assets will not be able to insulate their loan book from the shrinkage of their balance sheet following tighter monetary policy. Moreover, Kashyap and Stein use a two step estimation approach to allow for a different macroeconomic shock in each period for each geographical region which will reduce the possibility that changes in loan demand explain part of the estimated effects.

2.2.2. Standard monetary policy, bank capital and bank lending

The original formulation of the bank lending view, links monetary policy to bank lending through the effect of interest rates on bank deposits and the existence of frictions in the market of non-deposit liabilities. However, Kashyap and Stein (1993) also consider the effects of capital requirements on the transmission mechanism of monetary policy in a simple theoretical model and conclude that when capital requirements bind, for example after experiencing a capital loss, the effect of an expansionary monetary policy on bank lending are likely to be limited. This happens because capital requirements restrict the ability of banks to expand their balance sheet even though banks' liquidity increases following a monetary expansion. Even though this paper does not investigate empirically the role of capital requirements in the bank lending view, it introduces the notion that capital in the presence of regulatory capital requirements may affect the way in which monetary policy interacts with the banking system.

Van den Heuvel (2002) develops a theoretical model that explicitly takes into account the role of bank capital in the transmission mechanism of monetary policy. Given that the proportion of non-reservable liabilities in banks' balance sheets has increased, Van den Heuvel argues that the standard bank lending channel is weaker and that monetary policy affects bank lending also through bank capital. This transmission mechanism relies on the assumption that bank loans are slower to adjust than non equity liabilities so that an increase in interest rates reduces banks' profits. And assuming that equity cannot be issued costlessly, banks will reduce lending to rebuild their capital following a monetary tightening.

Gambacorta and Mistrulli (2004) and Gambacorta (2005) use a sample of Italian banks to show that bank capital has a crucial role in the transmission mechanism of monetary policy. First the authors show that better capitalised banks are less sensitive to tighter monetary policy as they are able to issue non-deposit liabilities at a lower cost than lower capitalised banks. Second, they find evidence that small banks are more affected by monetary policy shocks due to their elevated assets and liabilities maturity mismatch.

Gambacorta and Ibanez (2010) also argue that capital plays an important role in the transmission mechanism of monetary policy because poorly capitalised banks are more exposed to adverse selection problems and find that it is more costly to issue non-deposit liabilities following monetary tightening. Paravisini (2006) use a policy change in Argentina as an instrument to disentangle credit demand and supply and show that small and lower capitalised banks react more to a change in liquidity, in line with the studies above.

Jimenez et al. (2010) use Spanish firm and bank level data to test for the existence of the bank lending channel and to analyse the role of capital in the transmission mechanism of monetary policy. The use of bank and firm level data allows the authors to better disentangle the role of demand and supply on bank lending as they can observe at the same time the balance sheet of the lender and the balance sheet of the borrower for a given loan. Jimenez et al. find that changes in interest rates affect bank lending supporting the bank lending view. The effect on bank lending is somewhat larger than other papers (e.g. Kashyap and Stein (2000)) which the authors relate to the fact that other papers are not able to completely control for demand factors.[1] Moreover, the authors find that the effect of tighter monetary policy is stronger for poorly capitalised banks suggesting an important role for capital in the transmission mechanism of monetary policy.

These findings are in line with earlier studies using US banking data (e.g. Kishan and Opiela (2006)) which show that capital plays an important role in the transmission mechanism of monetary policy so that lower capitalised banks will be the most affected following tighter monetary policy.

2.2.3. Effects of unconventional monetary policy on the broader economy

There is now a large and growing literature that attempts to measure the macroeconomic impact of unconventional monetary policy. These policies affect a variety of economic variables and the functioning of the financial system; for example, QE in the UK affect nominal demand by boosting asset prices (financial market channel) and by increasing the monetary base and therefore bank lending (bank lending channel).[2]

Despite a broad based effect of QE on the financial system, large part of the literature has focused so far on the effects of unconventional monetary policy on financial markets and the broader economy. For example, Joyce et al. (2011) study the effects of gilts purchases by the Bank of England, the so called Quantitative Easing (QE), by using event studies and econometric analysis to show that asset purchases may have lowered gilt yields substantially. The authors also show that the effects on riskier assets may have come through mainly via the portfolio rebalancing effect, whereby sellers of gilts use

[1]This is because Jiminez et al. are able to account for observed and unobserved time-varying firm loan demand by including firm-quarter fixed effects.

[2]Section 3.3 will analyse in depth the transmission mechanism of QE.

money proceeds to bid up risky assets. Using US data, Gagnon et al. (2010) investigate the effect of Large Scale Asset Purchases (LSAP) by the Federal Reserve on financial markets and find that the LSAP has an economically strong and long lasting effect on long term interest rates on a variety of financial assets. Gagnon et al. also find that the reduction in long term interest rates reflects lower risk premia rather than lower expected policy rates.

Few papers analyse the effects of unconventional monetary policy on the broader economy. Chung et al. (2010) analyse the impact of Federal Reserve's asset purchases when short term interest rates are constrained by the zero-lower bound by using a set of econometric models. The authors find that asset purchases lowered the level of unemployment and probably prevented the US economy from falling into deflation. Similarly to Chung et al., Kapetanios et al.(2012) use a set of VAR models to estimate the effect of Quantitative Easing on inflation and economic growth in the UK. To construct the counterfactual the authors assume that QE lowers gilt yields as estimated in Joyce et al. (2011) and that QE affects the real economy only through lower gilt yields. In line with US empirical evidence, Kapetanios et al. find a sizeable positive impact of unconventional policy measures on economic growth and inflation. Bridges and Thomas (2012) use a simple money demand and supply framework to estimate the impact of QE on the UK economy and find that QE lowered gilt yields while increasing inflation, results that are broadly consistent with other evidence found on UK QE.

To our knowledge, little literature is available on the effects of unconventional monetary policy on bank lending and very few papers use panel data. Giannone et al. (2010) find that unconventional monetary policy measures in the Euro Area were successful in insulating the monetary transmission mechanism from the financial crisis. The authors use a Bayesian VAR to construct a counterfactual scenario that is then compared to the actual readings of economic variables and find that short term bank loans and M1 behaved during the crisis in line with pre-crisis regularities suggesting a positive effect of non-standard monetary policy on bank lending.

Carpenter et al. (2012) analyse the effects of non-standard monetary policies adopted by the Federal Reserve and the European Central Bank on bank lending. The authors first find that there exists a negative relationship between proxies for banks' funding costs and bank lending. They then use estimates from related research on the effects of unconventional monetary on banks' funding conditions along with their findings (e.g. Wu (2008)) to estimate the effects of unconventional monetary policy on bank lending in the US and the Euro Area.

Bowman et al. (2011) investigate the effects of Bank of Japan's quantitative easing programme in the early 2000s using a panel dataset of Japanese banks. They find that there is a statistically significant positive relationship between banks' liquidity position and bank lending so that quantitative easing, given its enhancing effect on banks' liquidity position, may have led to increased bank lending. However, the authors also find that the magnitude of the effect is not economically significant and that liquidity injections were effective only during the initial years of the programme when the financial system was impaired.

2.3. Current evidence on the effects of macroprudential policy

The role of capital on bank lending is well documented in the empirical literature. The main finding is that better capitalised banks lend more than poorly capitalised banks and that more capital helps banks isolating their lending schedule from adverse economic effects. The key problem in identifying the effect of capital on bank lending is disentangling supply and demand effects. If, for example, we observe that capital is declining along with lending this may be due to either a supply problem where the bank does not have enough capital to lend (a so called 'capital crunch') or a demand problem where bad macroeconomic conditions affect borrowers' creditworthiness and therefore banks' capital position and bank lending. Much of the empirical literature focuses on addressing this question using different identification strategies.

While the literature on the effects of capital on bank lending is well established, few papers have investigated the effect of regulatory *capital requirements* on bank lending. This relative lack of empirical research may be due to the fact that there have been few changes in capital requirements, which makes the relationship between capital requirements and bank lending difficult to identify. For example, the Basel I accord in 1988 established common minimum capital requirements of 8 per cent of risk-weighted assets initially adopted by major advanced countries and then implemented by other several countries worldwide. For studies exploiting the time-series variation around the implementation of Basel II it will be challenging to completely disentangle the effect of changes in capital requirements, demand factors and changes in the supervisory environment, e.g. examination standards (Jackson et al. (1999)), even though studies using US and European banks suggest that the introduction of Basel II may not have a significant impact on bank lending behaviour (Fabi et al. (2005), Liebig et al. (2007), Lang et al. (2008)). And cross-section analysis, e.g. across countries, will be affected by different institutional factors and differing bank variables definitions that are difficult to account for in the empirical analysis. Even though capital requirements were originally introduced as an instrument to enhance the resilience of the financial system rather than a time varying tool for macroprudential regulators, the recent development of macroprudential policy has attracted the attention of empirical economists trying to estimate the effectiveness of capital requirements as a macroprudential tool, for example in curbing excessive credit creation.

A branch of the literature in the UK investigate the effects of changes in time varying capital requirements on bank lending. The UK provides a unique natural experiment because capital requirements were set by the Bank of England and the FSA on a bank by bank basis, the so called 'trigger' capital requirements (capital requirements from now on), for more than two decades. These additional requirements were set by UK regulators starting in 1989 as the regulators felt that the Basel I Accord did not take into account a wide range of risks (e.g. interest rate risks, reputational and operational risks) that may affect firms' probability of default (Richardson and Stephenson, 2000). Capital requirements are usually set above the minimum regulatory capital and are mainly based on general market conditions, risk management practice and strength of individual banks' controls (FSA (2001), Francis and Osborne (2009)). If a bank breaches this 'trigger' level, regulatory action is taken. The capital requirements are set by the FSA on a bank by bank basis and vary over time (they are usually reviewed every 18-36 months) which allow the researchers to use it as a proxy for a macroprudential instrument.

However, these requirements were set for *micro*prudential reasons so that the estimated effect may be different when set by the *macro*prudential regulator. This is because the microprudential regulator changes the capital requirements based only on individual banks' riskiness while the macroprudential regulator aims to reduce systemic risk. For example, the microprudential regulator may not have increased capital requirements before the financial crises if all the financial institutions were individually sound but a macroprudential regulator may have increased capital requirements if it deemed the financial system over leveraged and therefore posing systemic risks.

This is not an exhaustive literature review but we will pick out the main papers that are closely related to our research, starting from the relationship between capital and lending and then turning to the effects of time-varying capital requirements on capital and bank lending in the UK.

2.3.1. Relationship between capital and lending

Bernanke and Lown (1991) use US state and individual bank level data to investigate the role of the capital crunch in the early 1990s recession. This paper tries to disentangle demand from supply factors by using bank level data from individual states so that the economic conditions facing local banks were similar across banks. In this case different responses in lending should be due primarily to shocks to capital rather than changes in demand. The authors find that the capital ratio has a positive, but economically small, effect on bank lending and that this result is mainly driven by small banks. Hancock and Wilcox (1998) use an instrumental variable approach on US banking data to correct for possible simultaneity bias and also find that shocks to capital affect bank lending.

Similarly to Bernanke and Lown, declines in capital affect small banks more than large banks.

Peek and Rosengren (1995) find that banks' balance sheets may have contracted sharply in the early 1990s not only because of capital losses but because of higher binding capital requirements around the implementation of the Basle I accord. As in Bernanke and Lown, they address the demand-supply nexus by restricting the sample to a single US state so that all the banks are facing the same macroeconomic conditions.

Peek and Rosengren (1997) was the first study using a natural experiment to investigate the effect of capital on bank lending. The authors exploit a sharp deterioration in Japanese banks' capital positions in the early 1990s, due to an unprecedented decline in Japanese equity prices, to show that lending of US branches of these banks declined more than other US banks. Given that lending by US banks was strong at the time, the authors conclude that the decline in lending by Japanese branches was due to the sharp deterioration in the capital position of Japanese parent banks, therefore establishing the existence of a strong supply effect. Their findings also suggest that the decline in lending by Japanese branches was exacerbated by the introduction of binding capital requirements (Basel I accord) and Japanese parent banks' attempt to insulate domestic borrowers from a credit crunch.

Jimenez et al. (2010, 2012b) use a unique dataset with firm and bank level data in Spain to better control for individual firm loan demand. The authors find that capital and liquidity positions of both banks and firms matter for the probability of granting a loan and that during a recession or when monetary policy is tight, banks with more capital and liquidity grant more loans than undercapitalised banks. This firm-bank level dataset helps addressing the identification issues that affect the majority of the empirical banking literature because it controls for both lenders *and* borrowers' balance sheets. The authors also find that the inclusion of firm specific effects increases strongly the effects of capital on lending so that previous studies are likely to underestimate the role of banks in the transmission mechanism of monetary policy.[3]

2.3.2. Effect of capital requirements on capital decisions

The studies reviewed in the previous subsection consider the effects of shocks to total capital ratios on bank lending. Given that changes in capital ratios reflect losses in the bank's loan or trading book which are often highly correlated with declines in economic activity, this may complicate the identification problem.

The focus of our research is on the effects of capital *requirements* on bank lending. A regulatory change in capital requirements also constitutes a shock to capital as banks will be able to use up less capital therefore decreasing their ability to extend new loans. However, banks may react differently to a change in capital requirements as regulatory actions convey information on the regulators' view on the riskiness of the bank. Following regulatory action, the bank may decide to change its behaviour by for example accumulating more capital to accommodate the new (heightened) capital requirement which in turn may have an effect on bank lending.

For this channel to exist, capital requirements need to affect total capital, i.e. capital requirements are binding. The link between capital requirements and capital is therefore a necessary condition for the transmission mechanism between capital requirements and

[3] This is because there is a higher degree of correlation between the amount of banks' capital and the type of borrower.

lending to exist. Below we briefly review research trying to investigate the effect of capital requirements on bank capital. Because of the availability of bank by bank capital requirements in the UK (as opposed to one off changes in capital requirements), this literature uses mainly data on UK banks.

Ediz et al. (1998) use a panel dataset of UK banks to investigate the effects of changes in individual banks' capital requirements on bank capital and lending decisions. Ediz et al. find that when regulators increase capital requirements banks increase their capital ratio. The authors also use their results to infer that banks reach their new desired capital ratio by issuing new capital rather than reduce the riskiness of their exposures.

Alfon et al. (2005) use a panel of UK banks to investigate the pass through of changes in capital requirements on banks and building societies' capital ratios. Similarly to Ediz et al., they find that banks and building societies adjust their capital ratios in response to changes in capital requirements. However, the authors also find that their reaction is asymmetric depending on whether financial institutions experience an increase or decrease in capital requirements.

Francis and Osborne (2009) estimate a dynamic panel model and data on UK banks for the 1998-2006 period and also find that changes in capital requirements affect banks' capital ratio. The authors also interact changes in capital requirement with the business cycle and find that the relationship between capital requirements and bank capital becomes stronger in an economic upturn than in a downturn. Moreover, Osborne et al. (2012) show within an error correction model framework that capital requirements affect banks' target capital and conclude that capital requirements are therefore binding.

In the US, the analysis on the effects of bank by bank capital requirements on bank capital is more limited. However, early literature (Peltzman (1970), Mingo (1975) and Dietrich and James (1983)) estimated the effects of regulatory target capital on a bank by bank basis (the so called 'ABC ratio') on banks' capital decisions and find inconclusive results. While Peltzman find that changes in ABC ratios do not have an effect bank capital ratios, Mingo use bank level data to show a positive effect of ABC ratios on bank capital. Dietrich and James analyse a different time period and conclude that Mingo results may have been driven by other regulatory factors rather than capital regulation.

More recently, Aggarwal and Jacques (1998) investigate the effect of Prompt Corrective Action (early regulatory intervention on problem banks) on banks' capital decision using a partial adjustment framework and found that PCA increased banks' capital ratio. Even though PCA does not involve changes in bank by bank capital requirements (as in the UK case), it represents, similarly to changes in UK trigger capital requirements, an increase in regulatory pressure on bank capital.

2.3.3. Capital requirements and bank lending

A new branch of banking literature is now emerging in the UK exploiting the fact that UK regulators have been setting time varying bank by bank capital requirements above minimum capital requirements. Differently from other studies this 'regulatory experiment' can be used as a proxy for macroprudential policy instruments (even though the intent of the regulator was primarily microprudential), such as the countercyclical capital buffer, as it allows to capture the effect of changes in capital *requirements* on capital decisions and bank lending. Our empirical research sits within this new branch of the banking literature.

Francis and Osborne (2010) use a partial adjustment model and panel data on UK banks to determine whether individual capital requirements set on a bank by bank basis by the regulator have an effect on target (i.e. desired) capital ratios. Differently from other partial adjustment models with target capital ratios (e.g. Hancock and Wilcox (1994)), Francis and Osborne include capital requirements as a determinant of the desired capital ratio, therefore isolating the effect of regulatory changes on banks' desired capital. The authors then use the gap from the estimated target capital ratio as a regressor in a lending equation to determine the effect of changes in capital requirements on lending. As in previous studies using UK data, Francis and Osborne find that capital requirements affect the desired level of capital, i.e. capital requirements are binding[4]. The authors also find that the gap between the target capital ratio and the actual capital ratio has a positive effect on lending so that when the actual capital is below the target capital banks shrink their balance sheet to rebuild their capital. The paper then uses the estimates on the effects of capital requirements on lending to simulate the effect of countercyclical capital buffers during the credit boom in the UK and find a negative and significant effect on the stock of bank lending and a positive impact on bank capitalisation levels after four years. Francis and Osborne then conclude that the use of countercyclical capital requirements may lead to a more resilient financial system.

[4]The term 'binding' capital requirements in the banking literature refer to capital requirements that affect the level of capital held by banks. This should not be confused with other terms used in the economics literature, e.g. binding constraints.

Ayiar et al. (2012) use a large panel dataset on UK banks to answer two main questions. First, the authors estimate the impact of changes in capital requirements on bank lending using a simple panel econometric model. Second, they estimate the impact of capital requirements on lending of UK resident foreign branches to study to what extent the effectiveness of capital requirements may be affected by other non-regulated financial institutions. The authors find that changes in capital requirements affect bank lending growth, results that confirm the role of capital requirements found in Francis and Osborne (2010). Moreover, Ayiar et al. also find that unregulated banks increase their lending in response to tighter capital requirements, so that the effect of capital requirements on total lending (i.e. lending by regulated and unregulated financial institutions) may not be as strong as estimated when taking into account only the regulated sector. The authors argue therefore in favour of an internationally agreed macroprudential policy framework that would reduce the potential for regulatory 'leakage'.

Studies on the relationship between capital requirements and bank lending are not limited to the UK. Jimenez et al. (2012a) analyse the impact of countercyclical capital requirements (so called dynamic provisioning in Spain) using a Spanish bank-firm level dataset which allows to better disentangle demand and supply factors. The authors first find that the introduction of dynamic provisioning led to a contraction in credit in 2000, while banks increased lending following a loosening of provisioning requirements in 2005. During the financial crisis in 2008, banks with higher buffers built in good times were able to reduce lending less than banks with lower buffers. This suggests that countercyclical capital buffers may smooth credit supply cycles. Watanabe (2007) shows the importance of tighter regulation in generating a credit crunch in Japan in the late 1990s. The author also shows that public capital injections led to an increase in lending which was not sufficient to offset the previous regulatory induced decline.

Differently from the other studies reviewed above, Osborne et al. (2012) analyse the effect of capital requirements on bank lending *rates,* rather than bank lending volumes, using an Error Correction Model (ECM). The model is estimated on individual banks to fully capture heterogeneity and allows to disentangle short and long term effects of capital requirements. The authors find a positive long-term relationship between the bank target capital, which is a function of capital requirements, and lending rates. Osborne et al. interpret this results as evidence of the existence of a cost of capital effect, i.e. higher target capital ratios lead to higher funding costs and therefore higher lending spreads. However, Osborne et al. also find that this relationship weakens significantly after 2007 because capital requirements are not binding when 'market' capital requirements dominate. This effect prevails because in times of financial crisis rising risk aversion increases the amount of bank capital required by market participants, which is often above the regulatory capital requirements. Finally, the authors find that short term deviations of capital from target capital does not affect lending rates and use this finding as evidence that banks with capital deficits do not use higher lending spreads to rebuild their capital buffers. From a policy perspective, these findings suggest that macroprudential policy may be effective in dampening a credit boom, while it may be less effective in boosting lending growth during periods of financial instability, i.e. the effects of capital requirements may be asymmetric through the credit cycle.

CHAPTER 3

Setting the scene

3.1. Introduction

One of the key problems of the current financial crisis in the UK is weak bank lending growth. For this reason, the Bank of England and the UK Government announced in July 2012 the Funding for Lending Scheme (FLS) to lower bank funding costs and support lending to the real economy (Bank of England (2012)). Supply factors (e.g. low bank capital and low liquidity buffers) and weak demand for bank lending have been identified as possible contributors to bank lending weakness (Bell and Young (2010)). These problems are the result of the fragility of the financial system that led to the crisis (for example excessive credit creation funded by an increase in leverage) and the unprecedented impact of the financial crisis on economic growth and bank lending demand. Macroprudential policy and unconventional monetary policy have a role in reducing excessive swings in credit growth that may generate financial and monetary instability.

The main objective of macroprudential policy is to monitor and reduce systemic risk which is 'the risk of developments that threaten the stability of the financial system as a whole and consequently the broader economy' (Bernanke (2009)). The establishment of macroprudential regulators was necessary as microprudential regulation is on its own necessary but not sufficient to reduce systemic risk (De Nicolo' et al. (2012)). For example, UK banks were individually robust before the financial crisis and there were rare failures of financial institutions, however their high leverage and interconnectedness meant that for a given macroeconomic shock the loss to the financial system was significant (Bank of England (2009)).

The close link between excessive credit creation and systemic risk[1] provides macro-prudential policy with the role of reducing swings in bank lending that may affect the stability of the financial system (Bank of England (2009)). Systemic risk can have a time series dimension, i.e. the build up of asset bubble and excessive credit creation and a cross sectional dimension, i.e. the risk that a failure of a major financial institution affect the stability of the financial system. In this section we will refer only to the time series dimension of systemic risk.

Changes in capital requirements are considered as one of the main tools available to macroprudential regulators. For example, the introduction of countercyclical capital buffers in Basel III Accord are based on capital add-ons that increase with the gap of credit/GDP ratio from its historical average (BIS (2010a,b)). Raising capital requirements during a lending boom forces banks to reduce their leverage either by cutting lending, issue fresh equity or a combination of the two (this effect is stronger if capital requirements are binding). All these actions are consistent with the objective of macroprudential policy of reducing systemic risk.

However, the task of estimating the impact of changes in macroprudential policy on bank lending and the broader economy is a challenging one. First, there is limited history on the use of macroprudential instruments as these tools were mainly adopted in Emerging Market economies since the early 1990s (Lim et al. (2011)). Second, a macroprudential

[1] For example when credit/GDP ratio increases compared to its historical averages, see BIS (2010a)

policy framework comprises a wide set of tools, for example changes in countercyclical capital buffers, leverage ratios and sectoral capital requirements (Bank of England (2012a)). Lim et al. provide a preliminary investigation on the role of macroprudential tools and show that these instruments may be effective in mitigating systemic risk. Moreover, Osborne at al. (2012) suggest that changes in capital requirements have an effect on bank lending.

Macroprudential policy is still at an early stage of development as only few central banks and regulators have started to put in place a policy framework similar to that developed for monetary stability. The Financial Policy Committee (FPC) in the UK, the European Systemic Risk Board (ESRB) in the EU and the Financial System Oversight Council (FSOC) in the US are early examples of macroprudential policy frameworks.

Turning to *unconventional* monetary policy, the objective of QE is to support demand in order to maintain monetary stability after reaching the zero lower bound. QE may therefore affect bank lending *indirectly* through demand for lending, but it may also affect supply *directly* if it also has an impact on bank balance sheet and profitability, for example by lowering bank funding costs.

It is difficult to clearly identify the fine line between conventional and unconventional monetary policies. In broad terms, monetary policy becomes unconventional when the instruments adopted by the central bank to achieve its goals differ from the instruments that are used in normal times. For example, before the financial crisis the Bank of England (BoE) implemented its monetary policy decisions by setting the interest rate at which it remunerated banks' reserves in a corridor system where banks periodically set their own reserves targets, the so called Sterling Monetary Framework (SMF) (Clews et al. (2010)).

However, the BoE departed from the SMF in March 2009 after the beginning of the QE programme and now implements monetary policy decisions by purchasing UK gilts financed by central bank money.

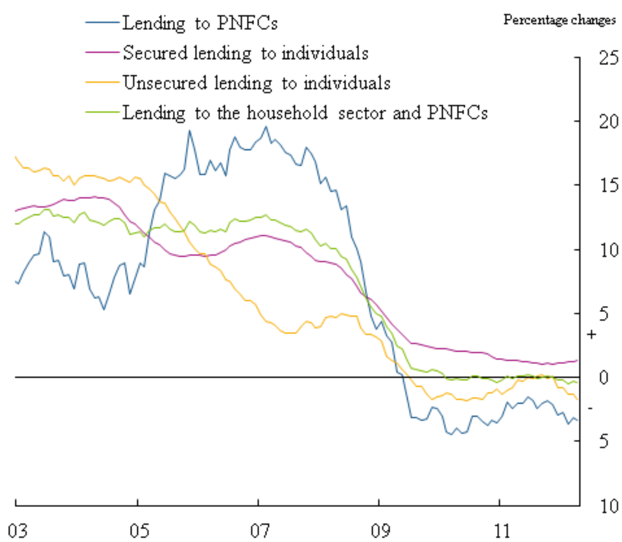
The key question is whether unconventional monetary policy was successful in boosting economic growth and restore the correct functioning of the transmission mechanism in order to support bank lending. Some empirical papers investigate the effect of unconventional monetary policies on financial markets (e.g. Joyce et al. (2011), Gagnon et al. (2010)), on the broader economy and bank lending (Kapetanios et al. (2012), Giannone et al. (2011) and Chung et al. (2011)) and generally conclude that these programmes were successful in easing market stress, boosting demand and enhance bank lending. Along with the Bank of England, other major central banks started unconventional monetary policy programmes, for example the European Central Bank with (among others) Long Term Refinancing Operations (LTRO) and the Federal Reserve with Large Scale Asset Purchases (LSAP) programme.

To set the scene for the theoretical and empirical papers, we first briefly outline the possible causes of the current crisis and effects of the crisis on the UK financial system. We then look at unconventional monetary policy and macroprudential policy and how they are transmitted to the financial system and we then briefly review initial findings on their effectiveness.

3.2. A brief review of causes and effects of the financial crisis

The causes of the current crisis have been well documented in the literature and generally include a combination of rising global imbalances, loose monetary policy and

Figure 3.1. Sectoral bank lending in the UK



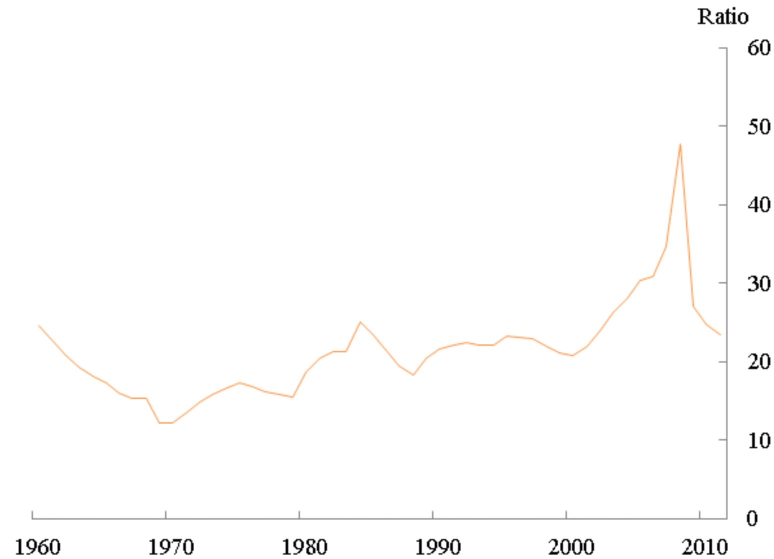
Source: Bank of England (2012).

inadequate banking supervision (Merrouche and Nier (2010)). We will not investigate the root causes of the current crisis, but we will briefly review some of the imbalances in the financial system that led to the current crisis and the subsequent sharp decline in bank lending. Given that the rest of the thesis focuses on the UK banking system we will only consider developments in the UK financial system.

Financial system leverage is an indicator of financial fragility because the higher the leverage the stronger the impact of a loss on banks' solvency position. In the run up to the crisis, UK banks expanded their balance sheet three-fold to around £7tn driven by increases in secured lending to households and lending to private non financial corporations. The increase in lending growth was particularly strong before 2007 but declined sharply after the financial crisis (Figure 3.1) .

The expansion in banks' balance sheet may be accompanied by increases in equity so that overall systemic fragility does not increase. However, Figure 3.2 shows that the

Figure 3.2. Leverage ratio for major UK banks



Source: Bank of England (2012).
(a) Ratio of total assets to shareholders' claims.
(b) The sample includes the following financial groups: Barclays, HSBC, LBG, National Australia Bank, Nationwide, RBS and Santander UK.

expansion in banks' balance sheet was mainly fueled by an increase in debt. Major UK banks' leverage increased sharply until 2008 to unprecedented levels in recent history. Bank leverage declined sharply following the financial crisis and has now reached levels more consistent with long run averages.

An increase in credit in itself is not necessarily detrimental to financial stability because it may be linked to a stronger economy and therefore stronger demand for lending. However, absent structural changes in the economy, credit growth should not be stronger than its norm based on economic fundamentals for a prolonged period of time. This is because excessive credit growth has been often associated with an increased probability of financial crises. For example, the gap between total credit and its long term trend is widely used by policymakers as a leading indicator for financial instability (Borio and

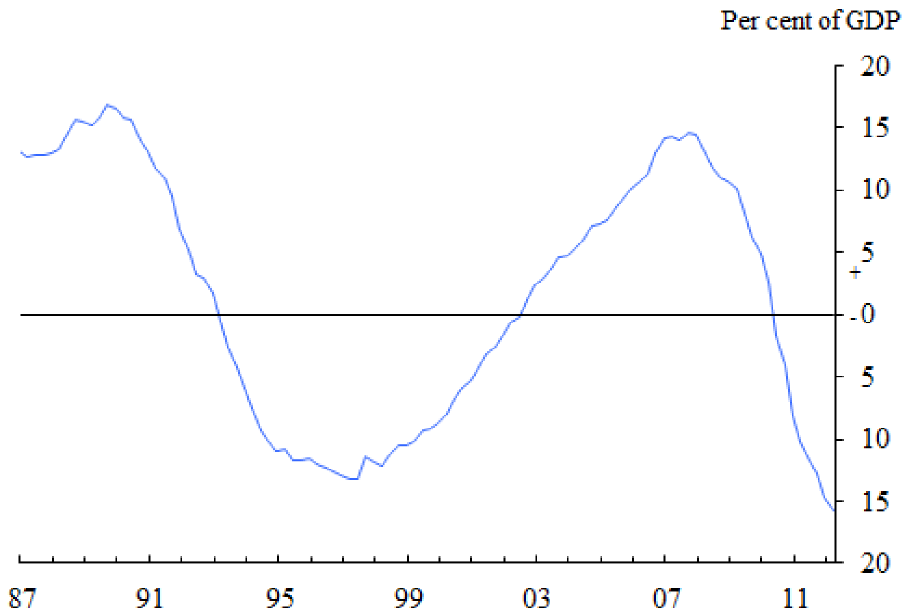
Lowe (2002)).[2] Figure 3.3 shows that the expansion in UK banks' balance sheet translated into excessive credit growth. The credit gap increased to around 15 per cent of UK GDP in 2007, while the most recent readings suggest that credit is well below its historical norm and comparable to the previous credit bust in the early 1990s.

Periods of credit exuberance are often followed by sharp credit contractions which may lead to monetary and financial instability. The contraction in credit in the UK following the financial crisis was particularly severe, even when compared with other recent systemic banking crisis in developed countries (Figure 3.4). Credit growth in the UK has been negative for around three years and only the latest data suggest a return towards nil growth.

While these charts do not tell us much about the drivers of the increase and subsequent fall in credit - they can be caused by both supply and demand factors - they suggest that policymakers had to take steps to address the sharp fall in credit demand and to prevent excessive credit growth. This is because falls in credit are important drivers of economic growth and they can affect financial stability as loss rates on loans increase and capital buffers decline. In the following sections we review the transmission mechanism of quantitative easing and macroprudential policy and we examine how these policies may affect bank lending.

[2] Long term trends for total credit are often estimated by using long term averages or Hodrick-Prescott filters.

Figure 3.3. Credit gap to GDP ratio in the UK

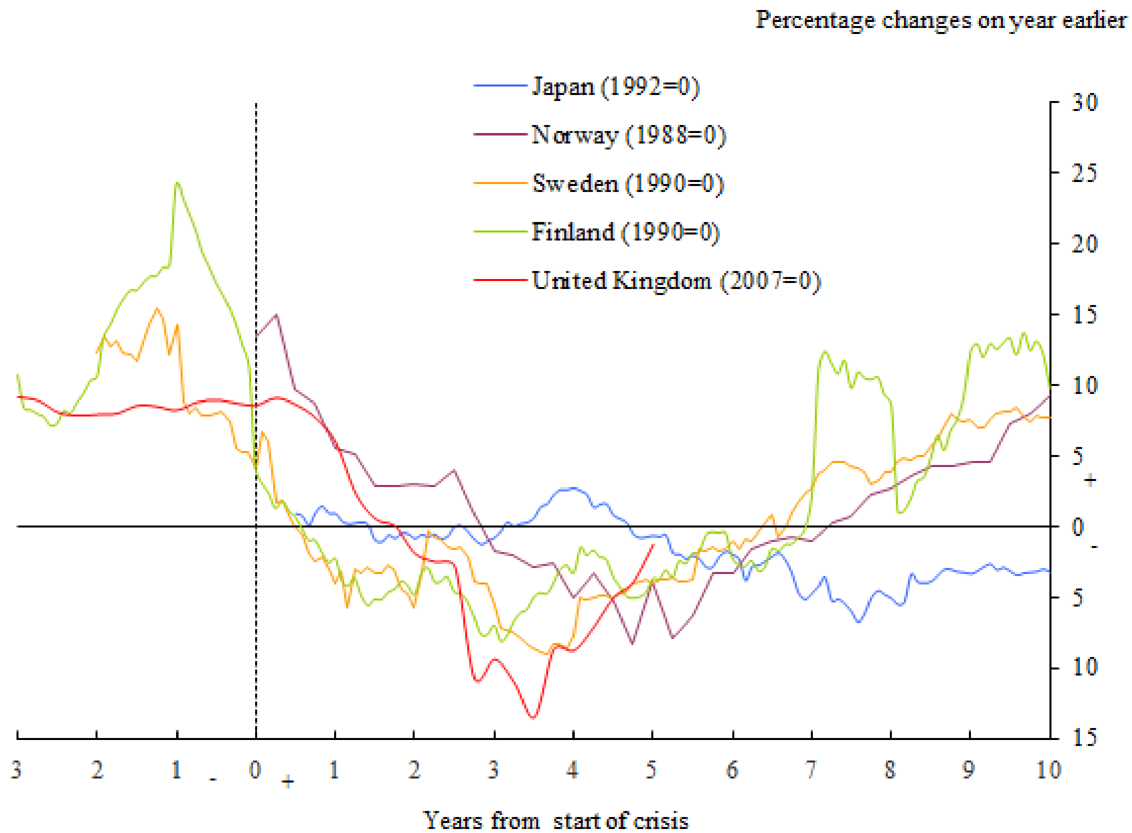


Sources: Bank of England (2012)
(a) Credit is defined as claims on the domestic private nonfinancial sector. The credit to GDP gap is calculated as the percentage point difference between the credit to GDP ratio and its long-term trend, where the trend is based on a one-sided HP filter with a smoothing parameter of 400,000.

3.3. The role of unconventional monetary policy during the crisis

In the previous section we suggest that excessive credit creation has an important role in increasing fragilities within the financial system and that credit has contracted sharply following the financial crisis. Contraction in credit has important implications for both monetary and financial stability. First, a reduction in credit affects the capacity of firms and households to fund investments and purchases of goods which in turn lowers economic activity. This means that for a given supply, the following decline in demand lowers inflationary pressures. Second, higher firms and households' insolvencies increase loans' write offs and therefore reduce bank capital buffers. Lower economic activity and a

Figure 3.4. Credit growth after sytemic banking crises

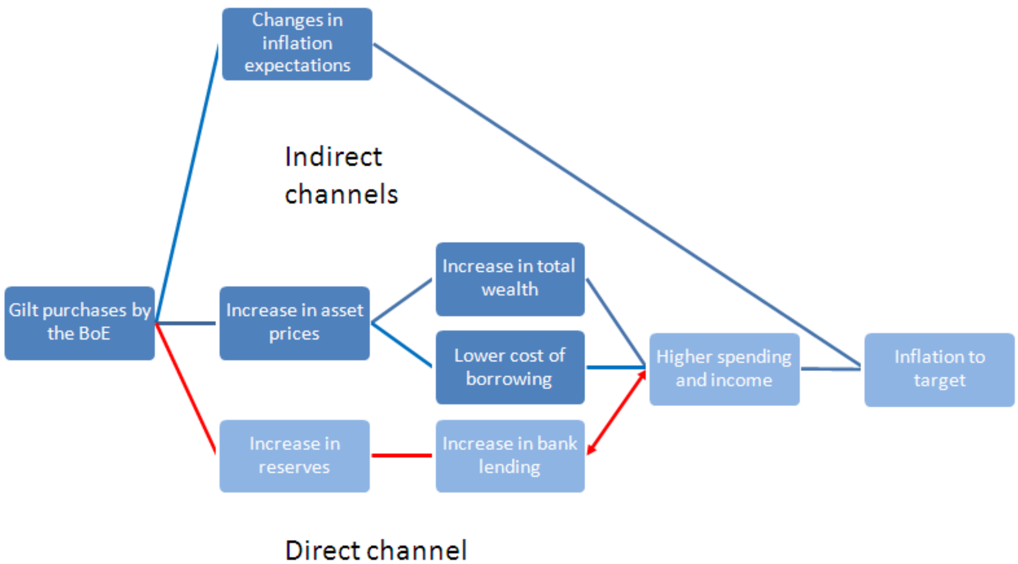


Sources: Bank of England (2012)
(a) Finland and Japan series represent bank lending, all other series represent lending by financial institutions.

more fragile (i.e. less capitalised) financial system affect demand and supply for lending and credit contracts even more.

Unconventional monetary policy in the UK can increase bank lending *indirectly* by supporting economic activity, and therefore demand for lending, and *directly* by changing the composition of banks' balance sheet (Figure 3.5). QE may therefore increase bank lending through three main economic channels: 1) effect on asset prices and portfolio

Figure 3.5. Transmission mechanism of QE



Source: Benford et al. (2009)

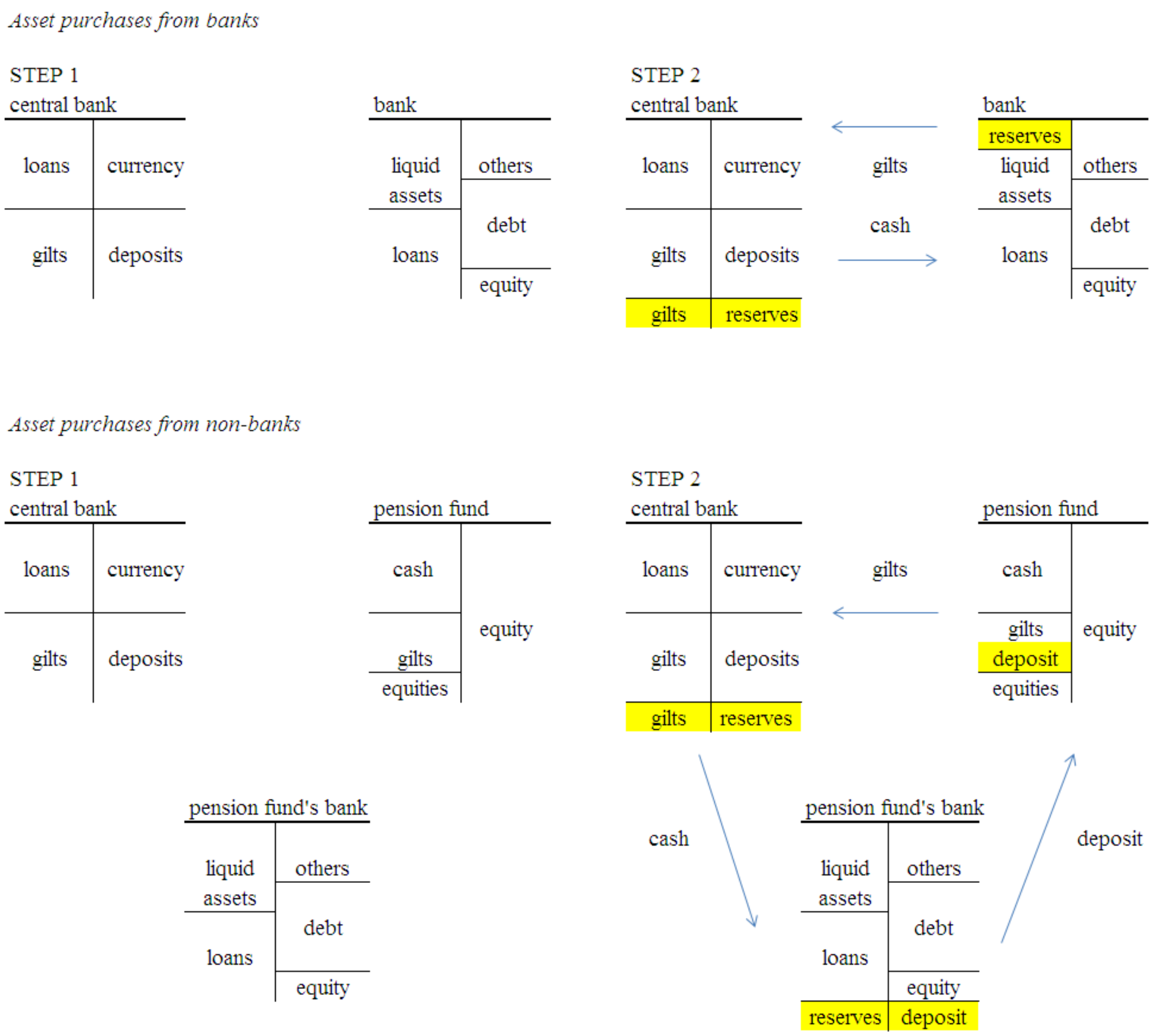
rebalancing; 2) bank lending and quantity effects; and 3) changes in expectations (Benford et al. (2009)). We now review these three channels in turn.

First, as the BoE purchases gilts financed by central bank money from non-bank financial institutions the balance sheet composition of these institutions change as non-bank financial institutions' deposits held at their banks increases as a share of total assets. After the gilts sale the non bank financial institution may want to rebalance its portfolio if the new deposits are not a perfect substitute of the gilts they sold the central bank, the so called 'portfolio rebalancing' effect. As financial institutions buy other assets (e.g. corporate bonds), the price of these and other instruments increases until the portfolio of the financial institutions is rebalanced, i.e. share of money in the portfolio reaches the desired level. This increase in asset prices lowers funding costs for corporates and increases household consumption through wealth effects which in turn boosts economic activity and inflation. Finally, higher spending and income boost demand for bank lending.

Second, quantitative easing may affect the supply of lending *directly* by increasing the liquidity of banks' balance sheet, the so called 'bank lending' effect. When the BoE purchases assets from non-bank financial institutions financed by central bank money, bank deposits and reserves at the central bank increase as the non-bank financial institutions deposit cash from the sale of gilts. Purchasing assets from non-bank financial institutions is a distinctive feature of BoE QE (as opposed to QE in Japan for example) and the main aim is to increase broad money as well as narrow money (Benford et al. (2009)). Figure 3.6 shows the direct channel of QE on bank lending from a balance sheet perspective, i.e. tracing the exchange of money across the financial system when assets are purchased from banks (e.g. QE in Japan) and when assets are purchased from non-bank financial institutions as in the UK. A higher level of reserves as a proportion of bank assets may increase banks' willingness to extend new loans as their precautionary motive for holding liquid buffers decreases (i.e. hold a buffer to avoid sudden liquidity problems) and banks may be willing to increase illiquid assets (e.g. loans) on their balance sheet.

Third, unconventional monetary policy in the UK may also affect bank lending indirectly via the expectations channel. The announcement of asset purchases should have a positive effect on inflation expectations as QE has the effect of reducing the probability of a deflationary scenario. In this case real interest rates will remain low enough to support investments and household spending. Moreover, the willingness of the central

Figure 3.6. Impact of QE on banks' balance sheet



bank to shore up the economy and maintain stable inflation may increase confidence and therefore economic growth.

There is a growing literature on the effects of unconventional monetary policy on financial markets and the broader economy (e.g. Joyce et al. (2011), Kapetanios et al. (2012), Chung et al. (2010)) but the literature on the effects of unconventional monetary policy on bank lending is more limited (especially using panel data) and to our knowledge there is no research that examines this effect in the UK.

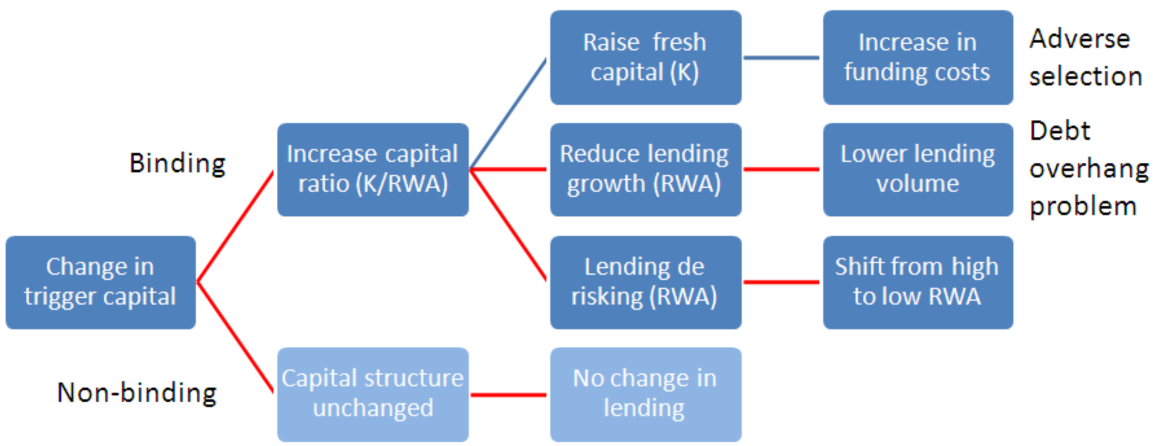
However, the empirical evidence so far seems to suggest that unconventional monetary policies in major economies may be effective in supporting bank lending growth. Bowman et al. (2012) examine the effect of Quantitative Easing policies on bank lending in Japan in the early 2000s using a panel data of Japanese banks and find that there is a positive but economically small effect on bank lending. Using aggregated data, Giannone et al. (2012) show that unconventional monetary measures taken by the ECB had a positive effect on bank lending and Carpenter et al. (2012b) reaches similar conclusions by using aggregated data on US and Euro Area banks.

3.4. Macroprudential policy: reducing the magnitude of financial crises

Sharp increases in credit like the ones experienced before the current financial crisis often lead to financial instability. While it is possible for the central bank to ease the sharp fall in demand by cutting interest rate and by using unconventional monetary policy, it is now widely accepted that central banks and regulators should avoid these excessive build ups in credit in the first place.

The objective of the macroprudential regulator is to monitor and reduce systemic risk and therefore it has a role in 'leaning against the wind' when credit growth is too strong. Given that the analysis of macroprudential policy is still at the early stages, there is no consensus on how changes in macroprudential policy may affect bank lending. In Figure 3.7 we present a possible transmission mechanism of capital requirements which is one of the instruments that may be used by the Financial Policy Committee in the

Figure 3.7. The transmission mechanism of changes in capital requirements



UK. Moreover, the literature on the effects of capital requirements on bank lending is the most developed and our empirical analysis will focus on this particular macroprudential instrument.

In a credit boom, the macroprudential regulator may want to reduce bank lending growth through an increase in capital requirements and lower them during a credit bust to support lending growth. An increase in capital requirements can be binding, i.e. it affects banks' capital ratios or non binding, i.e. banks do not change their capital structure following a change in capital requirements.

If the capital structure remains unaltered following a change in capital requirements, there should be no effect on bank lending as banks are 'comfortable' with a reduction in the capital buffer (i.e. capital above the capital requirement). However, the banking literature suggests that this is unlikely as banks try to hold a buffer above capital requirements to insure against the risk of breaching the regulatory minimum and being liquidated (Chami and Cosimano (2001)). Therefore we may expect that, for a given increase in capital requirements, banks will increase their capital ratio. This increase can be achieved in three ways: a) by raising fresh capital, b) by reducing lending growth and c) by de-risking the asset side of the balance sheet.

But given various frictions in the market for equity (e.g. adverse selection problem, Myers and Majluf (1984) and debt overhang problem, Myers (1977)) banks are likely to reduce lending rather than raise fresh capital (see also Hyun and Rhee (2011) for a theoretical model). Alternatively, banks can change the composition of their loan book without necessarily reducing total lending stock. Even in the event the bank decides to issue fresh capital, this may lead to an increase in bank funding cost given that equity is more expensive than debt and interest paid on debt are tax deductible. We would therefore expect that bank lending declines following an increase in capital requirements and empirical evidence on the effects of changes in capital requirements on lending supports the theoretical findings (VanHoose (2008)).

However, it is particularly difficult to identify an effect of changes in capital requirements (for example the introduction of Basel I or Basel II accords) on capital and lending because changes in capital requirements are rare events. For example, Jacques and Nigro (1997) investigate the effects of the Basel I accord on US banks in the year following its introduction in 1990. However, given that the US experienced a recession in 1991, their results may have captured both regulatory changes and demand factors. An interesting development in this literature is the use of bank-by-bank time-varying capital requirements set above the minimum capital requirements by UK regulators since late 1980s, the so called 'trigger ratios'. Before 2001 the Bank of England set the trigger ratios based on bank specific factors such as the quality of risk management, the quality of internal control and accounting systems, its size and outlook of markets where the bank was positioned. The power of setting 'trigger ratios' was passed over the FSA in 2001 and were set as a part of the Pillar 2 process.

To our knowledge, there is no other available information on other regulators setting capital requirements in this way so that the UK experience can be considered a macroprudential policy natural experiment. Aiyar et al. (2012) suggest that discretionary setting of capital requirements in the UK played a greater role than in other major countries. Of course, these capital requirements are set according to *micro*prudential rules but they can still be considered proxies for macroprudential tools.

Francis and Osborne (2010) and Osborne et al. (2012) suggest that changes in capital requirements are binding (i.e. affect banks' capital decisions) and that capital requirements have an effect on bank lending. Even though a macroprudential policy framework still needs to be implemented in major economies, these findings generally indicate that changes in capital requirements may have the desired effect in reducing bank lending.

CHAPTER 4

A Simple Theoretical Framework: Two Adverse Selection Models

4.1. Introduction

In this section we develop two stylised models to derive priors on the effects of Quantitative Easing (QE) and changes in capital requirements on bank lending. The key contribution of this chapter is the development of a consistent theoretical framework to examine the effects of QE and changes in capital requirements on bank lending. We will then test the predictions of the models in the following empirical chapters by using a newly constructed and non-publicly available panel dataset of UK banks.

The two models are based on Kashyap and Stein (1994) adverse selection model which is a simple partial equilibrium model with a stylised bank balance sheet and shocks to deposits that are driven by changes in monetary policy stance (e.g. a change in interest rates). Following these shocks the bank may decide to issue non-deposit liabilities if the stock of liquid assets is not enough to absorb the reduction in deposits. Loans cannot be liquidated so only securities can be drawn down following shocks to deposits.

The model is a simplistic description of how monetary policy affects bank lending. For example, the basic assumption is that changes in interest rates affect reserves and therefore the amount of deposits in the banking system. But this may not necessarily happen when changes in reserve requirements are not used as a monetary policy tool.

In the UK, during normal times, monetary policy is implemented by providing enough reserves to the banking system so that the short term interbank rate is close to the Bank rate and the amount of deposits in the system is determined by the banking system endogenously.[1] However, we will not need the link between changes in reserves and bank deposits to hold in our framework given that QE changes exogenously the level of total deposits in the banking system as gilts are (mainly) purchased from non-bank financial institutions.[2]

The key feature of this model is that, because of adverse selection, issuing non-deposit liabilities is costly so that a shock to deposits will lead to a change in bank lending, the so called 'bank lending channel'. Moreover, the standard Kashyap and Stein model also predicts that there is a different reaction of large and small banks as their costs of issuing non-deposit liabilities vary.

After examining the effects of QE on bank lending using this stylised model, we develop a simple new model where we include a shock to capital and derive a bank lending supply equation. Given that banks have to maintain a minimum level of capital (i.e. minimum capital requirements) we can then analyse the effects of changes in capital requirements on banks' lending. To identify the key predictions more easily we analyse the two models separately, as we will do with the empirical analysis in the following chapters. Of course, in reality there are interactions between QE and capital requirements but we leave this aspect of the analysis to future research.

[1] The Bank of England normal times framework is the so called 'Sterling Monetary Framework' established in 2006 and operational until 2009 when the QE programme started.

[2] See Chapter 3 for a detailed description of the transmission mechanism of QE on bank lending.

These simple models give us two testable predictions on the effects of QE and capital requirements on bank lending supply. First, the model predicts that an increase in deposits which follows QE (at least in the UK) leads to an increase in lending. Moreover, the effect of changes in deposits is stronger for small banks than for large banks because small banks find issuing non-deposit liabilities more costly. These results follow directly from the Kashyap and Stein model.

Second, changes in capital requirements will have a negative effect on bank lending. Therefore, increases in macroprudential capital buffers may be a useful tool in containing excessive credit creation. On the other hand, the model also suggests that these effects are heterogenous across banks. Large banks react less to changes in capital requirements than small banks because large banks face a lower cost of issuing capital.

We first review the existing theoretical literature on QE and bank lending in general equilibrium models and we then review the literature on capital requirements and bank lending from a partial equilibrium perspective. Finally, we present two simple (partial equilibrium) adverse selection models to analyse the impact of QE and capital requirements on bank lending.

4.2. The effects of QE and capital requirements on bank behaviour in general equilibrium models

The role of banks in modern macroeconomic models have been overlooked until recently (Goodhart (2009)). In standard micro-founded general equilibrium models money is generally introduced because of frictions (e.g. cash in advance requirements), but banks and money play a little role in model dynamics. Even in simple textbook IS-LM models, bank loans are grouped together with other assets in a bond market so that banks have only a 'passive role' (i.e. banks hold money as a liability) (see Bernanke and Blinder (1988)).

Kiyotaki and Moore (1997) do not include banks explicitly in their model but they develop a richer framework to analyse the relationship between asset prices and balance sheets, the so called 'financial accelerator' channel (in line with Bernanke and Gertler (1989)), that will be later applied to models with financial intermediaries. They introduce a macroeconomic model with endogenous credit constraints for borrowers where assets are used as collateral for loans and show that the effects of temporary shocks are magnified through a reinforcing effect on asset prices and borrowers' net worth.

Bernanke and Blinder (1988) extend the basic IS-LM model by including bank loans (in addition to money and bonds) which allows for an independent effect of bank loans on the real economy. However, the theoretical literature on the effects of unconventional monetary policies, including Quantitative Easing (QE), on bank behaviour has developed only recently, partly due to the challenges of introducing financial institutions in Dynamic Stochastic General Equilibrium (DSGE) models. For example, Gertler and Kyotaki (2010) and Gertler and Karadi (2011) analyse the effects of unconventional monetary policy actions with a DSGE model with financial frictions (based on Bernanke et al. (1999)) by adding endogenously determined balance sheet constraints for financial intermediaries and by introducing central bank intermediation as a monetary policy tool (e.g. the central bank can buy corporate debt in the secondary markets). In this framework, central bank balance sheet can expand during a financial crisis by issuing risk-free liabilities (in effect government debt) and it can increase its intermediation role while private sector balance sheets are shrinking. The authors find that the net welfare benefits of unconventional monetary policy may be large if efficiency losses are limited (they assume that central bank intermediation is less efficient than private intermediation) and these benefits may be even larger at the zero lower bound. These welfare benefits derive from the fact that central bank intervention is effective in reducing the wedge between lending and deposit rates, which in turn reduces the decline in investments. On the other hand, to our knowledge, there are currently no partial equilibrium theoretical models that study the effects of QE on bank behaviour.

More recently, also capital requirements have featured in DSGE models to study the effects of regulatory changes on bank behaviour and the real economy. Kiley and Sim (2012) develop a macroeconomic model where financial intermediaries optimally choose their funding structure showing 'financial accelerator' features. They then use the model to evaluate the effects of a countercyclical macroprudential policy - a tax on financial intermediaries' leverage which increases with indicators of potential financial imbalances (e.g. credit to output ratio). Simulations using the model show that while macroprudential policy tools may be effective in smoothing the cycle in response to financial shocks, macroprudential policy may be less desirable following non-financial shocks (e.g. productivity shocks). This is because bank lending is constrained when more credit is needed to acquire new capital which reduces investments and therefore economic activity.

Adrian and Boyarchenko (2012) develop a DSGE model with financial intermediaries in line with Gertler and Kyotaki (2010) and Gertler and Karadi (2011). However, they depart from these papers by assuming that financial intermediaries have to hold equity in proportion to the riskiness of their assets (i.e. as in Basel II where capital ratios are calculated as a proportion of risk-weighted assets), which gives the model a procyclical behaviour as suggested by empirical findings (see Adrian et al. (2011)). Adrian and Boyarchenko find that tighter capital requirements reduce banks' risk taking and therefore systemic risk in the future, but increases the price of risk today.

Goodhart et al. (2012) use a general equilibrium model with banks and non-bank financial institutions, to incorporate fire sales externalities that the relationship between banks and non-banks can generate, to estimate the impact of various regulatory measures on economic activity. They find that if the regulator raises capital requirements, the bank can either reduce mortgage lending or increase securitisation, which could potentially lead to credit 'leakages' from the banking to the non-bank financial sector.

4.3. Effect of capital requirements on bank lending in partial equilibrium models

The microeconomic theoretical literature to study the relationship between capital requirements and bank lending is more substantial than that on the impact of QE on bank lending. Myers and Majluf (1984) provides a theoretical rationale for the existence of an effect of capital requirements on bank lending. Because of asymmetric information, raising capital can be costly, and therefore affect banks' profitability and therefore banks' capital. If the capital requirement is binding, i.e. the bank increases its capital ratio following an increase in capital requirements, then this adjustment is more likely to come through cutting loans rather than issuing new costly equity. This may suggest that an increase in capital requirements is linked to a decline in lending.

Thakor (1996) uses a game theory model with asymmetric information to show that an increase in capital requirements raises the probability of a borrower being denied credit, therefore lowering the total banks' loan supply. This is because an increase in capital requirements increases bank funding costs (capital is more costly than deposits as in Myers and Majluf (1984)) which in turn reduces banks' profitability and makes investing in loans marginally less attractive. Following the increase in capital requirements banks therefore reduce the screening probability which in turn leads to credit rationing in equilibrium.

Zhu (2008) develops a dynamic stochastic partial equilibrium model to assess the impact of the transition from flat capital requirements to risk-based capital requirements as in Basel II. His analysis concludes that the transition to risk-weighted capital requirements does not necessarily lead to an increase in lending procyclicality. However, the introduction of risk-weighted capital requirements is likely to increase minimum capital requirements sharply for small banks (which in their model are riskier) leading to a large contraction in small banks' lending. However, Zhu does not directly study the effects of increases in capital requirements above Basel II requirements as in a macroprudential policy setting.

De Nicolo' et al. (2012) addresses this question more directly and builds on Zhu to study the impact of capital and liquidity regulation and taxation on bank lending, efficiency and welfare. They find that a low level of capital requirements (e.g. 4%) is consistent with an increase in lending compared to a case with no capital requirements. At the same time, a tightening of capital requirements (e.g. to 12%) has a significant negative impact on bank loans and reduces bank efficiency and social value. This is because it becomes too costly to issue equity to satisfy the increased capital requriements.

Therefore the relationship of capital requirements, lending and welfare has an inverse U-shaped relationship, reaching the maximum at the optimal level of capital requirements.

Hyun and Rhee (2011) suggest another possible transmission mechanism of capital requirements to bank lending. In their model the choice of reducing loan supply does not come because of the presence of asymmetric information but because an increase in equity capital, following an increase in capital requirements, will dilute existing shareholders which will find optimal replenishing the capital ratio by cutting loan supply instead. In this way Hyun and Rhee establish a negative relationship between capital requirements and bank lending.

4.4. A simple model on the effect of QE on bank lending supply

The Kashyap and Stein (1994) model is a two period model which allow us to generate a buffer stock motive for holding securities in the first period. On the asset side of the bank there are illiquid loans (L) and securities (S), e.g. UK gilts. On the liability side banks have equity (E), non-deposit liabilities (ND) and deposits (D). Equity is not included in the Kashyap and Stein model, but the main conclusions remain broadly unaltered.

Loans yield a return of r, and cannot be liquidated at time 2 capturing the illiquid nature of bank loans. Banks can invest S at time 1 yielding a normalised return of zero (r for the loan is therefore a spread) and the security can be costlessly liquidated at time 2. The spread r is a measure of the bank lending channel, i.e. how changes in monetary policy affect banks' returns.

In this model the level of deposits is determined entirely by the monetary authority so that when interest rates increase reserves decline and leading to a reduction in deposits, i.e. the monetary authority is able to affect banks' balance sheets through changes in reserves. This is of course an oversimplification of how monetary policy works in practice. However, we will not need the transmission mechanism from interest rates to changes in deposits to work in order to examine the effects of QE on bank lending as QE in the UK creates bank deposits directly because gilts are bought from non-bank financial institutions rather than banks.[3]

In this framework, when the amount of deposits at time 1 is realised, the distribution of deposits at time 2 follows a uniform distribution:

$$D_2 \text{ is uniform on } [\rho D_1 + (1-\rho)D - \gamma/2, \rho D_1 + (1-\rho)D + \gamma/2] \tag{4.1}$$

where the mean of D_2 is $\rho D_1 + (1-\rho)D$ and ρ is a measure of the persistence of the shock, while γ measures the variance of deposit shocks. D is the marginal effect of the monetary policy shock on the initial stock of deposits in the system, D_1. At time 2, the total quantity of deposits in the system is therefore D_2.

Following a shock to deposits (i.e. D_2 is realised) the bank can fund itself by issuing non-deposit liabilities (ND) and at time 2 the amount of non-deposit liabilities is ND_1(issued before the shock to deposits) $+ND_2$ (issued after the shock to deposits). The key assumption in this model is that there are increasing marginal costs of finance for non-deposit liabilities (ND) and that their costs are $\frac{\alpha_1 ND_1^2}{2}$ at time 1 and $\frac{\alpha_2 ND_2^2}{2}$ at time 2. This is because this type of liability is not covered by deposit insurance and large issuance of non-deposit liabilities may signal a bad state of the bank, the so called

[3]We will describe this mechanism more extensively in the following empirical paper on QE.

'adverse selection' problem. These costs are likely to be higher for small than for large banks (i.e. α_1, α_2 are larger for smaller banks) because large banks have better access to capital markets. Kashyap and Stein show empirically that this is true for a panel of US banks.

We also know that QE in the UK creates deposits so that increases in gilt purchases will be captured by shocks to D. When at time 2 the value of deposits is realized there are two possible cases:

1) $ND_1 + D_2 + E_1 > L$, then there is no need to issue external finance (ND) at time 2 and the bank can draw down the liquid asset buffer (S).

2) $ND_1 + D_2 + E_1 < L$, then the bank is short of funds and issues external finance (ND) at time 2 to absorb the shortage of funds.

The amount of non-deposit liabilities issued following the deposit shock will therefore be:

$$ND_2 = \max(0, L - ND_1 - D_2) \tag{4.2}$$

In order to write down the profit function we estimate the expected cost of issuing non-deposit liabilities at time 2 for the case of a deposit shock. In this case the expected issuance cost at time 2 from the perspective of the bank at time 1 is:

$$(4.3) \qquad E(\alpha_2 ND_2^2/2) = \alpha_2(L - ND_1 - \rho D_1 - (1-\rho)D - E_1 + \frac{\gamma}{2})^2/6$$

For the derivation of equation 4.3 see the Annex.

In the bank's profit equation, income is generated from loans and costs arise from non-deposit liabilities issued at time 1 and the expected costs of non-deposit liability issuance in the case of shock to deposits at time 2. Therefore, the bank's profit function will be the following:

$$(4.4) \qquad \pi = rL - \alpha_1 \frac{ND_1^2}{2} - \alpha_2(L - ND_1 - \rho D_1 - (1-\rho)D - E_1 + \frac{\gamma}{2})^2/6$$

Note that the expected cost at time 2 (equation 4.3) is the last term of equation 4.4. By differentiating 4.4 with respect to L and then ND_1 we can find the expression for bank lending supply and non-deposit liabilities, which is the same maximisation problem as in Kashyap and Stein with the only addition of the equity term E_1.[4] The lending supply equation can therefore be written as follows:

$$(4.5) \qquad L = \frac{3}{\alpha_2} r + \frac{r}{\alpha_1} + \rho D_1 + (1-\rho)D + E_1 - \frac{\gamma}{2}$$

Equation 4.5 suggests that an increase in deposits leads to an increase in lending so that an increase in bank deposits due to QE has a positive effect on lending. Also a higher

[4] We will not show the derivation of equation (4) as it is identical to Kashyap and Stein (1994).

level of equity (E) is related to higher bank lending.[5] This is in line with the 'bank capital channel' literature, e.g. Bernanke and Lown (1991), where shocks to capital affect bank lending.

As discussed before, we would expect large and small banks to react differently to a change in deposits given their different capacity to access capital markets. To analyse the effects of QE on large and small banks we differentiate 4.5 with respect to D_1. The first derivative can then be written as:

$$\frac{\partial L}{\partial D_1} = \left(\frac{1}{\alpha_1} + \frac{3}{\alpha_2}\right) \frac{\partial r}{\partial D_1} + \rho \tag{4.6}$$

Kashyap and Stein then assume a simple linear loan demand function to close the model of the form:

$$L_D = Y - kr \tag{4.7}$$

Equation 4.7 says that demand for loans is a positive function of economic growth and a negative function of the loan return r. Suppose there are n banks (our theory implicitly assumes banks are identical). Then the equilibrium condition is:

$$L_D = nL \tag{4.8}$$

[5]These results are effectively equal to the Kashyap and Stein's results with the exception that the loan supply equation is a function of E_1 too.

Let $b \equiv \frac{1}{\alpha_1} + \frac{3}{\alpha_2}$. Solving the equilibrium condition, we get:

$$r = \frac{1}{nb+k}\left(Y - n\left(\rho D_1 + (1-\rho)D + E_1 - \frac{\gamma}{2}\right)\right) \tag{4.9}$$

It then follows that:

$$\frac{\partial r}{\partial D_1} = \frac{1}{nb+k}\left(\frac{\partial Y}{\partial D_1} - n\rho\right) \tag{4.10}$$

If $\frac{\partial Y}{\partial D_1}$ is not too large (i.e. changes in deposits do not have a large impact on economic activity) then $\frac{\partial r}{\partial D_1} < 0$, which means that there exists a bank lending channel. In this case an increase in deposits reduces r, which is equivalent to an increase in the volume of lending. From equation 4.6 and 4.10 we can infer that, for a given change in deposits, banks that find more costly to issue non-deposit liabilities (e.g. small banks with high α_1 and α_2) will react more to a change in deposits. Conversely, large banks will react less to a shock in deposits.

Summing up, equations 4.5 and 4.6 give us two testable hypothesis. First, bank lending supply is positively related to deposits so that we should expect QE to increase bank lending. Second, small banks will react to QE more strongly than large banks. This is an intuitive result because small banks with limited access to capital markets are more likely to be credit constrained than large banks.

4.5. A simple model on the effects of capital requirements on bank lending supply

In the previous section we described the Kashyap and Stein model and analysed its implications for the effects of QE on bank lending. However, to our knowledge there is no consistent theoretical framework outlining the transmission mechanism of QE and capital requirements.

In this section we will use a modified version of the adverse selection model seen above to investigate the effects of changes in capital requirements on bank lending. In contrast to the previous model, banks face shocks to capital which has to remain above a binding capital requirement. These shocks may materialise because of losses in the loan book or mark to market losses in the trading book. We can then define the distribution of the shocks to equity (E), which will follow a uniform distribution:

$$E_2 \text{ is uniform on } [\rho E_1 + (1-\rho)E - \gamma/2, \rho E_1 + (1-\rho)E + \gamma/2] \tag{4.11}$$

The mean of the shock is $\rho E_1 + (1-\rho)E$ and γ is a measure of the variance of the capital shocks.

Banks respond to an equity shock by issuing non-deposit liabilities (ND) at time 1 and 2. The bank is not able to issue core equity because of the so called 'debt overhang problem' (Myers (1977)). This is because following a shock to capital investors will be unwilling to be the first in line to face losses. Therefore the bank can only issue Tier 2 capital (which is part of ND) which counts as total capital according to Basel II capital definition.

Banks are subject to minimum capital requirements and therefore have to maintain a constant equity/asset ratio $\delta = (E + ND)/A$ (i.e. minimum capital requirements), where the numerator is the total bank capital and the numerator is total bank assets.[6]

If the bank breaches the regulatory minimum δ (say at 8%) the regulatory authority takes the bank into resolution by liquidating the company and/or by transferring a part of its assets to another bank. Given that $A = (S + L)$ the equality above can be re-written as $\delta = (E + ND)/(S + L)$. At time 2 we observe the shock to capital and the bank may face two scenarios:

1) $\frac{E_2 + ND_1}{L+S} > \delta$, i.e. the bank is above the minimum capital requirement, then there is no need for new equity as the bank is solvent.

2) $\frac{E_2 + ND_1}{L+S} < \delta$, i.e. the bank breaches the minimum capital requirements, then the bank is insolvent and needs to issue new capital (ND).

In this case the amount of non-deposit liabilities (ND) issued by the bank at time 2 will be:

$$ND_2 = \max(0, \delta(S + L) - (E_2 + ND_1)) \tag{4.12}$$

[6]The definition of capital ratio is a simplified version of the Basel II definition, where the numerator is risk-weighted assets.

The expected cost of issuing non-deposit liabilities at time 2 can then be written as follows:

$$E(\alpha_2 ND_2^2/2) = \alpha_2(\delta(S+L) - \rho E_1 - (1-\rho)E - ND_1 + \frac{\gamma}{2})^2/6 \tag{4.13}$$

We have now all the main terms of the bank's profit equation. The profit of the bank increases with the interest charged on loans and the volume of loans while decreases non linearly with non-deposit liability issuance at time 1 and time 2. The main difference from the previous model is the expected cost of non-deposit liability issuance which is now a function of regulatory minimum (δ) too. Using 4.13, the bank's profit equation will have the following form:

$$\pi = rL - \alpha_1 \frac{ND_1^2}{2} - \alpha_2(\delta(S+L) - \rho E_1 - (1-\rho)E - ND_1 + \frac{\gamma}{2})^2/6 \tag{4.14}$$

By differentiating the profit function 4.14 with respect to L and then with respect to ND_1 we obtain the bank's loan supply function for a representative bank (see Annex for proof):

$$L = \frac{3}{\delta}\left\{\alpha_1\Phi[\rho E_1 + (1-\rho)E] + \frac{(3\alpha_1+\alpha_2)\Phi}{\delta} r - \Phi\alpha_1\frac{\gamma}{2}\right\} - S \tag{4.15}$$

Where Φ is equal to $\frac{1}{\alpha_2(3\alpha_1+\alpha_2-1)}$.

Given that L is a positive number the term of equation 4.15 in brackets has to be positive. This means that for an increase in capital requirements δ, lending stock (L) will decline. This result is in line with the theoretical literature on the relationship between capital requirements and bank lending (e.g. Hyun and Rhee (2010), Van Hoose (2007)) and will be used to test our empirical model.

Changes in capital requirement δ affect lending through two channels. First, an increase in capital requirement leads banks to delever as they try to reduce the issuance of costly non-deposit liabilities. Second, a higher δ also decreases lending by reducing the sensitivity of changes in lending to changes in lending returns (see the δ term inside the brackets). So if returns r increase because of better macroeconomic conditions, banks' lending will adjust less to this increase. This can be explained by the fact that higher minimum capital requirements reduce bank risk taking as the probability of falling below the minimum increases.

Kashyap and Stein show (also empirically) that in an adverse selection setting large and small banks react differently to a monetary policy shock. Similarly, large and small banks may expect to have a different impact on lending following a change in capital requirements. This is because large and small banks may face different costs of issuing capital following a capital shock.

If we assume for simplicity that $\alpha_1 = \alpha_2$, i.e. the cost of issuing non-deposit liabilities is the same at time 1 and time 2 then Φ is positive for $\alpha > \frac{1}{4}$, i.e. the cost issuing non-deposit liabilities is non-negligible. In this case for an increase in capital requirements lending declines because issuing non-deposit liabilities is costly and banks will restore the capital ratio by cutting lending. This is similar to the mechanism at work during the current crisis where shocks to capital were followed by declines in lending because of high cost of issuing new capital.

The story is slightly different when $0 < \alpha < \frac{1}{4}$ and Φ is negative, i.e. capital is cheap. In this case an increase in the capital requirement has a smaller impact on lending than in the previous case (proof in the Appendix). This means that for banks with a lower cost of capital the effect on lending is still negative but likely to be limited. These results are intuitive as lower cost of capital means that banks can issue non-deposit liabilities following an increase in the capital requirement rather than cut lending and/or dispose of its assets.

Using equation 4.15 we can, with some more algebra, derive an expression for $ND_1$to analyse the effect of changes in capital requirements on the issuance of non-deposit liabilities. ND_1 can be then written in the following way:

$$ND_1 = \alpha_2 \Phi \left\{ (1-\alpha_2)\left[\rho E_1 + (1-\rho)E\right] - (1-\alpha_2)\frac{\gamma}{2} + \frac{3}{\delta} r \right\} \tag{4.16}$$

When Φ is positive (i.e. $\alpha > \frac{1}{4}$, raising capital is costly), an increase in the minimum capital requirements leads to a decline in the issuance of non-deposit liabilities. This is because capital is costly and an increase in capital requirements is met by a shrinkage of the bank balance sheet. On the other hand, when Φ is negative ($0 < \alpha < \frac{1}{4}$, raising capital is cheap), an increase in minimum capital requirements leads to an increase in non-deposit liabilities. This is because part of the increase in capital requirements is met by issuing new Tier 2 capital.

4.6. Conclusions

We consider two simple, partial equilibrium adverse selection models to form our priors on the effects of changes in deposits and changes in minimum capital requirements on bank lending supply. We use an adverse selection model developed by Kashyap and Stein (1994) and we incorporate shocks to capital and a binding capital requirement.

We find that changes in deposits (e.g. following QE) have a positive effect on bank lending supply, and for a given change in deposits small banks are likely to react more than large banks. We also find that an increase in minimum capital requirements reduces bank lending and that a given change in capital requirements will affect small banks more strongly than large banks. This is because small banks find issuing equity more expensive than large banks. Additionally, if the cost of equity rises for all the banks a change in capital requirements may have a sharp effect on bank lending.

These results are consistent with large part of the theoretical and empirical literature on the bank lending channel and the effects of capital requirements on bank lending. We will then test these four predictions in the next chapters using a newly constructed panel dataset of UK banks.

Appendix

4.A. Appendix

Derivation of equation 4.3

$E(\alpha_2 ND_2^2/2) = \alpha_2(L - ND_1 - \rho D_1 + (1-\rho)D - \gamma/2 - E_1 + \frac{\gamma}{2})^2/6$

We know that the first moment of a uniform distribution is $E(X) = \frac{1}{2}(a+b)$

And the second raw moment of the uniform $E(X^2) = \frac{a^2+b^2+ab}{3}$

$E(\alpha_2 ND_2^2/2) = \frac{\alpha_2}{2}E(ND_2^2) = \frac{\alpha_2}{2}E(\max(0, L - ND_1 - D_2 - E_1))^2$ (the RHS quantity is uniformly distributed between 0 and the bigger positive quantity with $\gamma/2$, we then use the definition of second raw moment)

$$= \frac{\alpha_2}{2}\frac{(L-ND_1-\rho D_1+(1-\rho)D-E_1+\frac{\gamma}{2})^2}{3} = \alpha_2(L-ND_1-\rho D_1+(1-\rho)D-E_1+\frac{\gamma}{2})^2/6$$

Derivation of equation 4.13

$\mathrm{E}(\alpha_2 ND_2^2/2) = \alpha_2(\delta(S+L) - \rho E_1 - (1-\rho)E - ND_1 + \frac{\gamma}{2})^2/6$

$\mathrm{E}(\alpha_2 ND_2^2/2) = \frac{\alpha_2}{2} E(ND_2^2) = \frac{\alpha_2}{2} E(\max(0, \delta(S+L) - E_2 - ND_1))^2$(use the same principle as above)

$$= \frac{\alpha_2}{2} \frac{(\delta(S+L) - \rho E_1 - (1-\rho)E - ND_1 + \frac{\gamma}{2})^2}{3}$$

Derivation of equation 4.15

$$\frac{\partial \pi}{\partial L} = 0 \rightarrow 3r - \alpha_2 \delta^2 L = \delta(\delta \alpha_2 S - \rho E_1 - (1-\rho)E - ND_1 + \frac{\gamma}{2})$$

$$\rightarrow L = -S + \frac{1}{\alpha_2 \delta}[\rho E_1 + (1-\rho)E] + \frac{1}{\alpha_2 \delta} ND_1 - \frac{1}{\alpha_2 \delta}\frac{\gamma}{2} + \frac{3}{\alpha_2 \delta^2} r \quad (*)$$

$$\frac{\partial \pi}{\partial ND_1} = 0 \rightarrow 3\alpha_1 ND_1 + \alpha_2 ND_1 = \left\{\alpha_2 \left[\delta(S+L) - \rho E_1 - (1-\rho)E + \frac{\gamma}{2}\right]\right\}$$

$$\rightarrow ND_1 = \frac{\alpha_2 \delta}{3\alpha_1 + \alpha_2} S + \frac{\alpha_2 \delta}{3\alpha_1 + \alpha_2} L - \frac{\alpha_2}{3\alpha_1 + \alpha_2}\left[\rho E_1 + (1-\rho)E\right] + \frac{\alpha_2}{3\alpha_1 + \alpha_2}\frac{\gamma}{2} (**)$$

Now we can plug in our expression for ND_1 (**) into L (*) we have derived above.

$$L = -S + \frac{1}{\alpha_2 \delta}[\rho E_1 + (1-\rho)E] + \frac{1}{3\alpha_1 + \alpha_2} S + \frac{1}{3\alpha_1 + \alpha_2} L - \frac{1}{\delta(3\alpha_1 + \alpha_2)}\left[\rho E_1 + (1-\rho)E\right] + \frac{1}{\delta(3\alpha_1 + \alpha_2)}\frac{\gamma}{2} - \frac{1}{\alpha_2 \delta}\frac{\gamma}{2} + \frac{3}{\alpha_2 \delta^2} r$$

$$\rightarrow \left(1 - \frac{1}{3\alpha_1 + \alpha_2}\right) L = -\left(1 - \frac{1}{3\alpha_1 + \alpha_2}\right) S + \left[\frac{1}{\alpha_2 \delta} - \frac{1}{\delta(3\alpha_1 + \alpha_2)}\right]\left[\rho E_1 + (1-\rho)E\right] + \left[-\frac{1}{\alpha_2 \delta} + \frac{1}{\delta(3\alpha_1 + \alpha_2)}\right]\frac{\gamma}{2} + \frac{3}{\alpha_2 \delta^2} r$$

$$\rightarrow L = -S + \left[\frac{3\alpha_1}{\alpha_2 \delta(3\alpha_1 + \alpha_2 - 1)}\right]\left[\rho E_1 + (1-\rho)E\right] - \left[\frac{3\alpha_1}{\alpha_2 \delta(3\alpha_1 + \alpha_2 - 1)}\right]\frac{\gamma}{2} + \left[\frac{3(3\alpha_1 + \alpha_2)}{\alpha_2 \delta^2 (3\alpha_1 + \alpha_2 - 1)}\right] r$$

$$\rightarrow L = \frac{3}{\delta}\left\{\left[\frac{\alpha_1}{\alpha_2(3\alpha_1 + \alpha_2 - 1)}\right]\left[\rho E_1 + (1-\rho)E\right] + \left[\frac{(3\alpha_1 + \alpha_2)}{\alpha_2 \delta(3\alpha_1 + \alpha_2 - 1)}\right] r - \left[\frac{\alpha_1}{\alpha_2(3\alpha_1 + \alpha_2 - 1)}\right]\frac{\gamma}{2}\right\} - S$$

Proof of relationship between cost of capital and effect of capital requirements on lending

We are now in the case of $0 < \alpha < 1/4$. If we rewrite the lending supply equation in the following way:

$$L = \Phi\frac{3}{\delta}\left\{\alpha_1[\rho E_1 + (1-\rho)E] + \frac{(3\alpha_1+\alpha_2)}{\delta}r - \alpha_1\frac{\gamma}{2}\right\} - S$$

Then we can see that if $\Phi\frac{3}{\delta} < 0$, also the part of the equation within parenthesis will have to be negative for the equation to hold (remember that L has to be a positive quantity). For an increase in δ , this component will increase. On the other hand when the other δ within the parenthesis increases the quantity within parenthesis will become even more negative.

To determine which of the two effects dominates we have to see for what values $3\Phi > (3\alpha_1 + \alpha_2)$. This is true for $\alpha < 1$, so for every α within $0 < \alpha < 1/4$.[7] Therefore, given that the left-hand side always dominates, an increase in minimum capital requirements reduces lending, but less than in the $\alpha > 1/4$ case.

Derivation of equation 4.16

To derive equation 4.16 we plug in the early expression for L, as in (*), in (**), which are the two first derivatives of the profit function with respect to L and ND respectively.

$$ND_1 = \left(\frac{\alpha_2}{3\alpha_1+\alpha_2}\right)\left\{\delta S + \delta L - [\rho E_1 + (1-\rho)E] + \frac{\gamma}{2}\right\}$$

[7] Recall that we assume that $\alpha_1 = \alpha_2$.

$$\rightarrow ND_1 = \left(\frac{\alpha_2}{3\alpha_1+\alpha_2}\right)\left\{\frac{1}{\alpha_2}\left[\rho E_1 + (1-\rho)E\right] + \frac{1}{\alpha_2}ND_1 - \frac{1}{\alpha_2}\frac{\gamma}{2} + \frac{3}{\alpha_2\delta}r - \left[\rho E_1 + (1-\rho)E\right] + \frac{\gamma}{2}\right\}$$

$$\rightarrow \left(\frac{3\alpha_1+\alpha_2-1}{3\alpha_1+\alpha_2}\right)ND_1 = \left(\frac{1}{3\alpha_1+\alpha_2}\right)\left[\rho E_1 + (1-\rho)E\right] - \left(\frac{1}{3\alpha_1+\alpha_2}\right)\frac{\gamma}{2} + \left(\frac{3}{\delta(3\alpha_1+\alpha_2)}\right)r +$$
$$-\left(\frac{\alpha_2}{3\alpha_1+\alpha_2}\right)\left[\rho E_1 + (1-\rho)E\right] + \left(\frac{\alpha_2}{3\alpha_1+\alpha_2}\right)\frac{\gamma}{2}$$
$$\rightarrow ND_1 = \alpha_2\Phi\left\{(1-\alpha_2)\left[\rho E_1 + (1-\rho)E\right] - (1-\alpha_2)\frac{\gamma}{2} + \frac{3}{\delta}r\right\}$$

Proof of relationship between cost of capital and effect of capital requirement on non-deposit liability (ND) issuance

It is quite straightforward to see that when Φ is positive an increase in capital requirements leads to a decline in non-deposit liabilities. However, when Φ is negative and the minimum capital requirement increases, non-deposit liabilities increase too.

$$ND_1 = \alpha_2\Phi\left\{(1-\alpha_2)\left[\rho E_1 + (1-\rho)E\right] - (1-\alpha_2)\frac{\gamma}{2} + \frac{3}{\delta}r\right\}$$

CHAPTER 5

Quantitative Easing and Bank Lending: A Panel Data Approach

"*A significant programme of asset purchases was likely to be necessary in order to make up this shortfall in nominal spending. The current strains in the financial system, and in particular the pressures on banks to reduce the size of their balance sheets, meant banks were less likely to increase their lending substantially following an increase in their reserves…The Committee noted that …asset purchases were likely to be most effective if they were purchased from the domestic non-bank financial sector rather than from banks.*"

MPC Minutes, 4 and 5 March 2009

5.1. Introduction

After the global financial crisis worsened at the end of 2008, the major central banks cut their policy rates sharply and, after hitting the zero lower bound, began looking for other unconventional measures to loosen monetary conditions further. In the United Kingdom and United States, a key element of these unconventional measures has been the policy of large-scale asset purchases financed by central bank money, sometimes referred to as quantitative easing (QE).

In the United Kingdom, the Bank of England's Monetary Policy Committee (MPC) announced a policy of asset purchases financed by central bank money in March 2009, at the same time as it reduced Bank Rate to 0.5%, its effective lower bound. In announcing the new policy, the Committee noted that without further measures there was a serious risk inflation would undershoot the 2% inflation target in the medium-term. By the end of the first round of purchases that ended in January 2010 the Bank of England had purchased £200 billion of assets, consisting almost exclusively of government bonds - an amount equivalent to 14% of annual nominal GDP (see Joyce, Tong and Woods (2011)). In October 2011, the Bank resumed its QE purchases and at the time of writing (March 2013) has purchased a total of £375 billion of assets.

There is now a large and growing literature that attempts to measure the impact of central bank asset purchases during the financial crisis in the United Kingdom and elsewhere. Most of this literature focuses on the impact of asset purchases on financial markets (for the UK, see for example, Joyce et al (2011) and for the US, Gagnon et al (2010)) and to a lesser extent the wider economy effects (for the UK, see Kapetanios et al (2012) and Bridges and Thomas (2012) and for the US Chung et al (2011)), but there has been very little analysis of the effects of asset purchases on banks (a study by Bowman et al (2011) of the effects of QE in Japan is an isolated example but their analysis relates to the 2001-2006 period rather than the recent crisis). This relative neglect reflects the general consensus that the main effects of QE have come through increasing asset prices, through signalling and portfolio balance effects (see e.g. Joyce, Tong and Woods (2011)).

As the quote above from the MPC's March 2009 Minutes indicates, the MPC specifically downplayed the possibility of QE working through a bank lending channel because of the pressures on banks to deleverage in the crisis. This was reflected in the design of the purchase programme itself, which was targeted towards the non-bank financial sector by skewing purchases towards medium and long-term maturity gilts, rather than the shorter-maturity gilts typically held by banks for their liquidity needs. But, even if all the Bank's

QE asset purchases came from non-banks (directly or indirectly), the banking sector will still have gained additional reserves as a result, as well as a corresponding increase in its deposits. These additional reserves mean that banks' holdings of liquid assets will have increased, making them less reliant on seeking wholesale funding to manage their liquidity needs. Put another way, the extra deposits that banks consequently held will have helped relieve any funding constraints they may have faced. Since these constraints are more likely to bind in times of financial stress, it seems possible that this might have led to additional lending.[1] While any effects on lending might have been expected to be weak during a period when the banks were also trying to delever, it seems unlikely that there will have been no effect at all. In other words, relative to the counterfactual of no QE, bank lending seems likely to have been larger.

The contribution of this chapter is to test for the existence of this bank lending channel and to quantify the size of the effects of the Bank of England's QE policy during 2009-10 on bank lending using a new non-publicly available quarterly panel dataset on UK banks. The use of this unique dataset allows us to model the relationship between bank lending growth and its determinants over a twenty-year period pre-dating the financial crisis and to explore whether the relationship between deposits and bank lending changed during the crisis. We are also able to explore heterogeneities between large and small banks and to control for the balance sheet effects, by including information on bank capital ratios at the level of individual banks. Given that (by construction) QE affects the amount of bank deposits, we first estimate the historical relationships between bank lending growth and deposit growth, macroeconomic indicators and individual controls. In order to simulate

[1] This potential channel has been highlighted by David Miles in various speeches, see 'Asset prices, saving and the wider effects of monetary policy', 1 March 2012.

the potential effects of QE on bank lending, we first estimate the impact of QE on the amount of bank deposits and then use the econometric estimates to gauge the impact on bank lending.

We find that QE may have led to small but statistically significant increases in bank lending. The effect on bank lending is heterogeneous, as small banks have increased lending more than large banks, consistent with economic theory. However, we also find evidence that the effect of QE on bank lending may have been smaller than initially estimated because of lower levels of capital during the crisis.

The rest of this paper is structured as follows. The next section discusses the MPC's asset purchase programme during 2009 to 2010 and how these purchases may have affected bank balance sheets and bank lending. Section 3 describes the non-publicly available panel dataset on UK banks that we have used to examine the effects of QE on UK banks during the crisis. Section 4 turns to the econometric strategy we adopt, while Section 5 discusses the econometric results and some simulations of the likely effects of the first round of the Bank of England's QE purchases on bank lending. The final section concludes.

5.2. Quantitative easing and its impact on banks

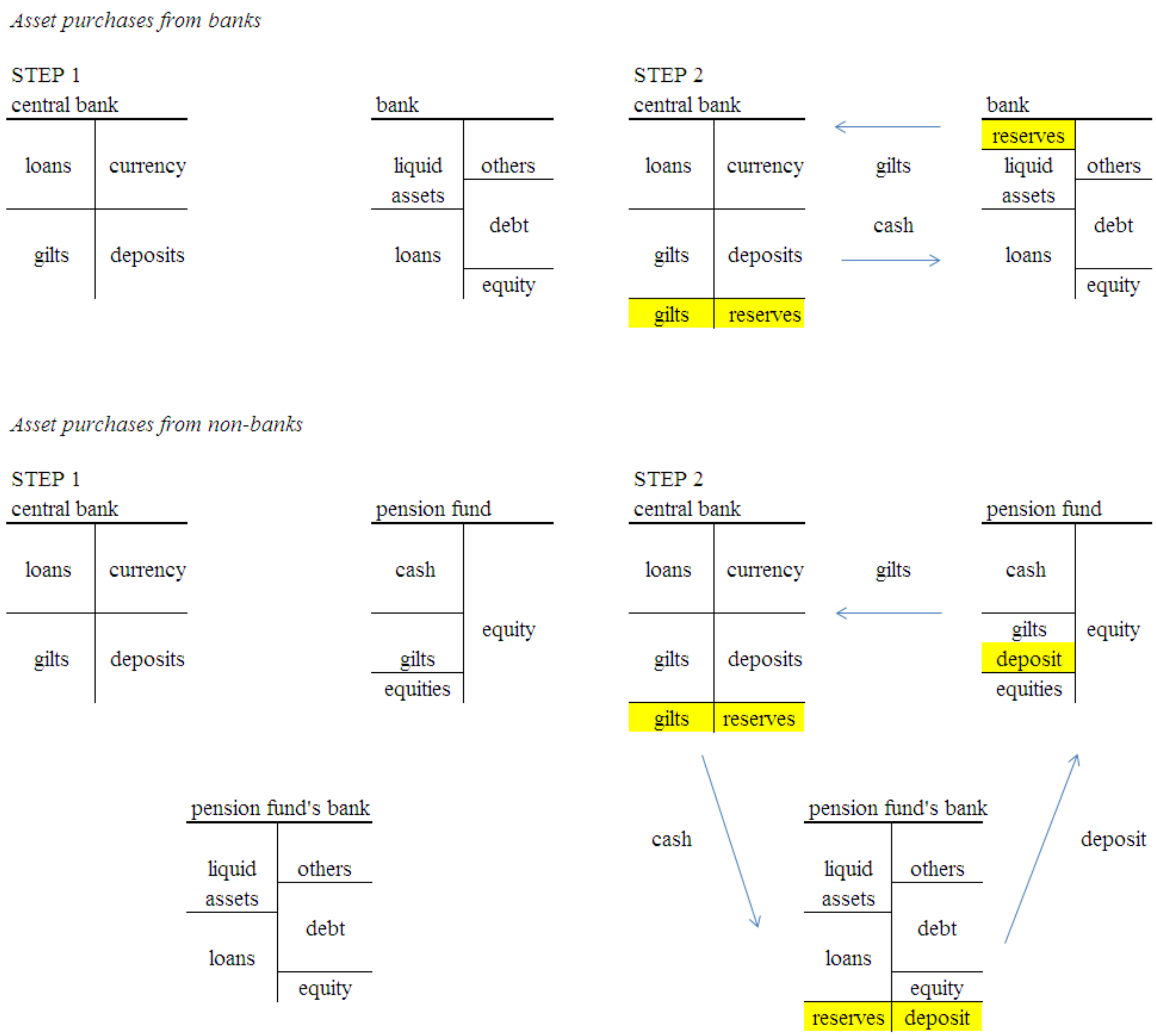
The Bank of England's MPC announced the beginning of its first round of QE asset purchases in March 2009. The initial decision was to purchase £75 billion of assets over a three-month period, but further extensions to the programme were subsequently announced at the May, August and November 2009 MPC meetings and by the time the programme was paused in early 2010 the Bank had bought £200 billion of assets. Though the Bank purchased some private assets, the overwhelming majority of the purchases consisted of UK government bonds (so-called gilts). Initially the Bank bought gilts with a residual maturity of between 5 and 25 years, although this was later extended to gilts with maturities of 3 years or over. Part of the motivation for purchasing medium to long-term bonds was to skew purchases towards the non-bank financial sector (insurance companies and pension funds) rather than buying from banks (see Joyce, Tong and Woods (2011)).

From a balance sheet perspective, central bank asset purchases from *banks* constitute an exchange of Gilts for reserves on the bank's asset side as the central bank credits the bank's reserve account with central bank money in exchange of the asset purchased. Because reserves are higher, narrow money increases (i.e. monetary base or currency in circulation plus reserves held at the Bank of England) but broad money (i.e. currency in circulation plus deposits) remains unchanged. At the same time the central bank expands its balance sheet by the amount of the assets purchased (Figure 5.1). The Bank of England has purchased gilts mainly from non-bank financial institutions (e.g. pension funds and insurance companies) with the intention of increasing not only narrow money but also broad money via an increase in deposits (Benford et al. (2009)).

When the Bank of England purchases assets from non-bank financial institutions (e.g. a pension fund) it credits the bank of the pension fund with central bank reserves, while the pension fund gains a deposit at its bank. Differently from the case where assets are purchased directly from banks, this asset purchase has increased the bank's balance sheet (Figure 5.1).[2] The bank finds itself with a more liquid balance sheet on the asset side (a

[2]We present a simplified version of the asset purchases scheme. In practice, asset purchases are completed via an off-balance sheet vehicle rather than the Bank of England directly. However, this does not affect our econometric strategy.

Figure 5.1. Effects of QE on banks' balance sheets



higher reserves ratio) and more deposits on the liability side. Given that the bank now has a higher level of liquid assets, and possibly above the one required to meet payment demands from customers, it may be less costly for the bank to increase lending to the real economy (e.g. lending to households or non-financial corporations).

Initially the 'new' deposits will be from non-bank financial institutions. However, if non-bank financial institutions use the cash to buy higher yielding assets (e.g. corporate bonds), the deposit moves to the private non financial corporate sector. If the bank then lends to an household to purchase a flat, it also creates new household deposits. This means that it is likely that the bank's deposit mix will change over time, but in reality it is difficult (if not impossible) to track these changes through the banking system. In this paper we will therefore use total rather than disaggregated measures of deposits.

Asset purchases by the central bank may also have *indirect* (flow) effects on banks' balance sheet. For example, if these purchases affect long rates and the slope of the yield curve this can have an effect on banks' net interest margins (NIM). This in turn may affect the ability of banks to accumulate capital and extend new lending to the real economy. For example, Alessandri and Nelson (2012) show empirically that interest rates and the slope of the yield curve affect NIM using data on UK banks. In this paper we focus only on the *direct* balance sheet effects, i.e. reaction of banks' lending following changes in the *stock* of deposits. In order to do this, we use a non-publicly available panel dataset containing balance sheet and income statement information of individual banks. Before turning to our econometric analysis, the next section describes this dataset.

5.3. Data

The new panel dataset includes non-publicly available quarterly balance sheet and income statement data of 30 financial institutions active in the lending market operating in the UK from Q2 1989 until Q4 2010. The sample includes UK-owned banks, foreign-owned banks (around 60% of the sample), building societies (around 10% of the sample) and non-bank financial institutions (around 17% of the sample). The panel is unbalanced as the time series is discontinued after mergers and failures - banks are observed for a minimum of 9 periods and a maximum of 92 periods.[3]

We have included financial entities on a consolidated level, as we assumed that lending decisions are taken on a group-level basis. Considering a lower level of consolidation (as for example in Kashyap and Stein (2000)) would instead assume that liquidity could not be transferred within the group and that subsidiaries act in isolation. Given that this is an unrealistic assumption, we think that a consolidated approach better reflects the relationship between liquidity and lending in a complex banking group. This is consistent with Houston, James and Marcus (1997) who found that shocks to one subsidiary in a holding company are partially transmitted to other subsidiaries in the banking group.

Table 5.1 describes the main variables used in this paper. Total lending is obtained by adding the stock of lending to households and to private non-financial corporates (PNFC), i.e. total non-financial lending. 'Total lending growth' is calculated as the quarter over quarter percentage changes of total lending stock, while 'provision ratio' is defined as provisions over assets ratio. 'Changes in capital ratio' is capital over risk-weighted assets quarter over quarter change and 'Changes in deposit ratio' is quarter over quarter changes in total deposits over total assets ratio.

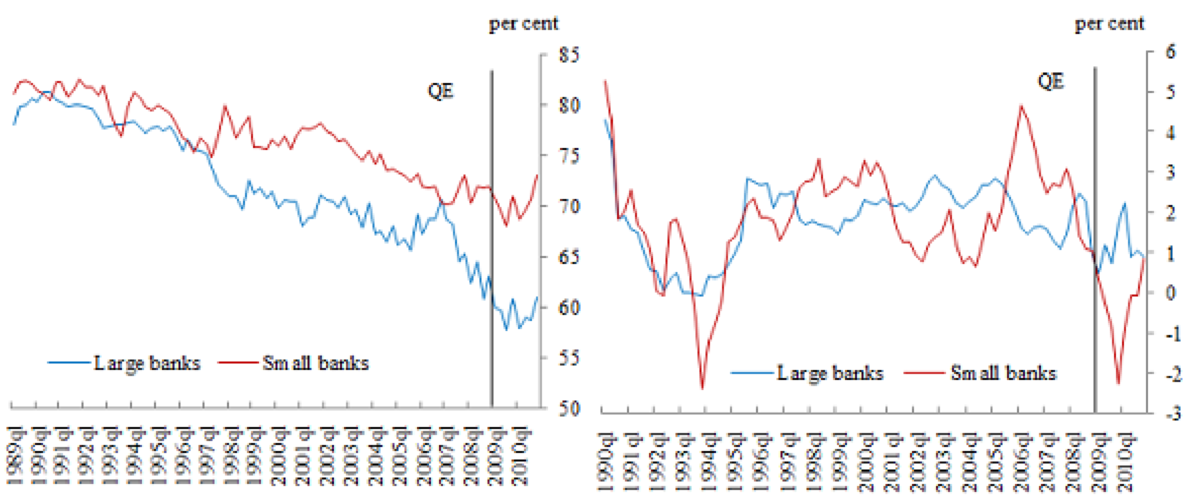
We have summarised these variables for large and small banks, where a large bank is any bank that has been on the top five according to assets at any period during the

[3]An alternative approach adopted in the literature is to construct 'artificial' banks that are observed along the whole time series. Even though this approach is likely to reduce problems deriving from the use of unbalanced panel data, it may create estimation biases. For example, following a merger, unobservable characteristics of the bank (e.g. management ability) may change but this 'structural' change would not be picked up in the estimates if we used 'artificial' banks.

Table 5.1. Description of the main variables (1989-2010)

Variable	Obs	Mean	Std. Dev.	Min	Max
Total					
Total lending growth (%)	3336	1.8	8.5	-23.1	34.8
Capital ratio (%)	2777	15.1	5.4	10.2	42.0
Provision ratio (%)	3945	0.3	1.0	-2.5	15.5
Capital buffer change (pp)	2361	0.0	1.3	-16.0	17.2
Change in deposit ratio (pp)	3578	-0.2	4.3	-36.9	43.9
Large banks					
Total lending growth (%)	473	1.8	3.3	-15.5	28.3
Capital ratio (%)	527	11.9	1.3	10.2	17.1
Provision ratio (%)	725	0.3	0.3	0.0	3.1
Capital buffer change (pp)	470	0.0	0.4	-2.8	1.6
Change in deposit ratio (pp)	476	-0.2	2.5	-8.5	11.8
Small banks					
Total lending growth (%)	2863	1.8	9.0	-23.1	34.8
Capital ratio (%)	2250	15.8	5.7	10.2	42.0
Provision ratio (%)	3220	0.3	1.1	-2.5	15.5
Capital buffer change (pp)	1891	0.0	1.4	-16.0	17.2
Change in deposit ratio (pp)	3102	-0.2	4.6	-36.9	43.9

Figure 5.2. Deposit over asset ratio and total lending growth



sample.[4] Large and small banks have similar averages for total lending growth, provision ratio and changes in deposit ratio, but small banks' variables exhibit a higher dispersion. This is because large banks have more homogenous characteristics, while small banks range from medium sized to very small institutions.

Figure 5.2 (left-hand side panel) shows the deposit over asset (DA) ratio for large and small banks in our sample. The DA ratio has declined steadily since early 1990s consistent with the fact that banks have increasingly financed their assets with non-deposit liabilities. Since the late 1990s large and small banks' DA ratio started to diverge and became structurally lower for large banks. Better access to capital markets by large banks and the evolution of more complex funding instruments (e.g. securitisation) probably explains the different behaviour of large and small banks.

The DA ratio ticked up around the second half of 2009 (particularly for small banks) which may be seen as evidence that QE had an effect on the banks included in our sample. However, we should not over interpret the evidence from this chart, as this increase is comparable to previous increases in the series and more data is needed to judge whether this is 'noise' or a structural increase in DA ratio due to QE.

Figure 5.2 (right-hand side panel) shows that both large and small banks' lending growth declined during the crisis compared to pre-crisis averages. But small banks' lending growth turned negative shortly after the QE programme started while large banks' lending growth remained in positive territory. Small banks' lending growth then increased strongly since 2010 Q1. Our dataset therefore suggests that there might be differences in the way large and small banks reacted to QE.

[4] Throughout the sample the same eight banks are classified as large.

5.4. Econometric strategy

The bank lending channel literature (e.g. Kashyap and Stein (1993)) suggests that deposit growth is positively related to lending growth. This literature builds on the imperfect substitutability of bank deposits with non-deposit liabilities to show that a monetary shock (e.g. increase in interest rate) has an impact on bank lending. The argument goes that a monetary tightening reduces bank deposits as bank reserves are drained from the banking system. If banks want to maintain a stable ratio of reserves over deposits, a reduction in the numerator has to imply a reduction in the denominator too.[5] Banks will have then to increase their share of non deposit liabilities to maintain the size of the balance sheet unchanged. However, banks may not have access to capital markets or non-deposit liabilities may be more costly (e.g. because of adverse selection and/or lack of deposit insurance), and they may shrink their balance sheet by cutting lending to accommodate the decline in deposits. Kashyap and Stein (2000) provide empirical evidence that the so called 'bank lending channel' exists using a large panel of US banks.

As discussed in Section 5.2, Quantitative Easing (QE) may affect lending through changes in deposits. This channel is similar to the bank lending channel, with the exception that in this case the central bank affects directly the amount of bank deposits in the financial system via asset purchases. Our strategy is therefore to use the QE-induced change in deposits to estimate the effect of QE on bank lending.

However, following QE not only the level of deposits increases, but also deposits over total assets (DA) ratio increases. We will focus on DA ratio as it ensures that we are not

[5]In practice modern central banks do not change monetary policy by changing reserve requirements. However, we do not need this link between interest rates and deposits for our econometric strategy to work, as QE changes directly the stock of deposits in the banking system.

capturing increases in deposits that are in line with growth of other non-deposit liabilities. By looking at the ratio we will capture only those large changes in deposits that 'drive' the increase in assets and are therefore closer to a QE-induced expansion of banks' deposits.

At the same time, we are interested in what happens to the *level* of lending following an increase in the DA ratio. After the asset purchase the bank has an additional amount of reserves on its balance sheet and the bank can then decide whether to lend some of these reserves out (e.g. to households). The focus in this paper will be on lending *growth* because we would like to capture changes in the level of lending following changes in DA ratio.[6]

Using lending growth as dependent variable is quite common in the literature. For example, Kashyap and Stein (2000) investigate the existence of the bank lending channel mechanism by regressing bank lending growth on individual bank variables and macroeconomic factors. Bernanke and Lown (1991) study the effect of changes (and level) in the capital ratio (i.e. capital over assets) on lending growth.

Assuming that QE affects banks mainly through changes in deposits, we can then investigate the effect of changes in the DA ratio on lending growth. Using equation 5.1 we can estimate the importance of the bank lending transmission mechanism of QE in the following way:

$$\Delta l_{it} = \alpha + \beta(L)\Delta l_{it} + \gamma(L)\Delta D_{it} + \delta(L)\Delta C_{it} + \mu' I_{it} + \theta' A_t + u_{it} \tag{5.1}$$

[6] Other possible left hand side variables, e.g. lending over asset ratio, are not useful for our purpose because this ratio may remain unchanged even though banks decide to increase lending to the real economy.

where Δl_{it} is quarterly lending growth for bank i in period t, ΔD_{it} is changes in the deposits over assets ratio, ΔC_{it} is changes in the published regulatory capital (capital over risk weighted assets), I_{it} is a vector of micro controls and A_t is a vector of macro controls. u_{it} is a normally distributed error term with mean zero and variance $\sigma^2, u_{it} \sim N(0, \sigma^2)$.[7] L is a lag operator where $\beta(L) = \sum_{s=1}^{4} \beta_s(L^s)$, $\gamma(L) = \sum_{s=2}^{3} \gamma_s(L^s)$ and $\delta(L) = \sum_{s=1}^{2} \delta_s(L^s)$. We use lagged dependent variables to reduce the simultaneity bias problem in our estimates.

This dynamic (Auto Regressive Distributed Lag) model allows us to estimate both short and long-run effects of changes in the deposit ratio on lending growth. The short-run effects are identified by the coefficients of the individual time lags, while the long-run effect is identified by the sum of the lagged coefficients divided by one minus the sum of lagged lending coefficients.[8] In the following section we will present both long run and short run estimates.

According to 5.1 lending growth is a function of individual bank characteristics (capturing lending supply factors) and macroeconomic variables (capturing lending demand factors). Among bank characteristics we have included the size of the bank, changes in the ratio of provisions over assets and changes in regulatory capital ratio (regulatory capital over risk weighted assets). The size of the bank is likely to be linked to the bank's business model and therefore to lending growth, while the provisions ratio is an indicator

[7] Moreover, we assume that the error terms are independent both in time and cross-section dimensions, i.e. $E(u_{it}, u_{js}) = 0$ for $i \neq j, s \neq t$.

[8] Using this specification we are able to estimate the long run effects of changes in deposit ratio on bank lending growth. This effect is defined as the cumulative effect of a change in deposit ratio on lending growth as time goes to infinity. However this effect should not be confused with the effect on the long-run lending growth, which we constrain to be zero. This is because the model is estimated in growth rates and there is no long-run levels relation.

of asset quality which affects the bank's capacity to lend. Changes in the capital ratio affect lending because capital is a costly source of funding. A low *level* of capital ratio (i.e. close to the regulatory minimum) also provides a limit to lending growth. We have also included a control variable to account for differences in sectoral demand that may drive lending growth as in Aiyar (2011).[9]

The macroeconomic controls include GDP growth, unemployment rate, FTSE 100 growth and Bank Rate. All these variables are likely to drive lending demand. For example, stronger GDP growth will increase household income and therefore demand for secured lending.

If QE had an effect on bank lending we would expect $\gamma(L)$ to be positive and statistically significant so that an increase in DA ratio leads to higher lending growth. Similar literature on this issue is limited at the moment, and therefore it is difficult to have strong priors on the sign and magnitude of the effect, even though the bank lending channel literature points towards a positive relationship between deposit growth and bank lending.

However, according to the Monetary Policy Committee of the Bank of England, the effect of an increase in bank reserves on bank lending may have been muted during the banking crisis given the incentives of banks to deleverage.[10] One of the advantages of this

[9]Total lending is calculated by adding lending to households (secured and unsecured) and lending to private non-financial corporations (PNFC). If a bank is particularly exposed to lending to PNFCs and there is a specific demand shock to this sector we would observe total lending for this particlar bank to decline sharply. To reduce the impact of secoral demand shocks on our estimates we have included a variable calculated as follows as in Ayiar (2011):
$\Delta S_{i,t} = \Delta l(s)_t * (\frac{l(s)_{i,t}}{totlending_{i,t}}) + \Delta l(u_t) * (\frac{l(u)_{i,t}}{totlending_{i,t}}) + \Delta l(p_t) * (\frac{l(p)_{i,t}}{totlending_{i,t}})$
where the changes in sectoral lending are computed by excluding changes in sectoral lending by the bank we are considering.

[10]See minutes of the monetary policy committee meeting on 4 and 5 March 2009 available at http://www.bankofengland.co.uk/publications/minutes/mpc/pdf/2009/mpc0903.pdf, p. 9 paragraphs 31 and 34.

study is that our panel dataset allows us to control directly for this factor by including changes in bank-by-bank capital ratios in our baseline regression.

Throughout the paper we are going to treat this panel dataset as a *time-series* panel dataset, as we would expect that our results will be largely determined by the time-series dimension within individual banks. Indeed for changes in total lending and changes in DA ratio (our key variables), within (individual bank) variance explains almost all total variance. This indicates that the cross-section dimension is not likely to contribute much to our estimates.

The relevance of the time-series dimension in the panel dataset may add two potential problems to the estimation process. First, the variables we have included in the specification may not be stationary, and this may cause our estimated relationship to be spurious. However, we consider changes for most of the variables, so that even if they were originally integrated of order one, taking changes would make them stationary.

Second, including the lags of the dependent variable generates biased estimates, the so-called 'lagged dependent variable' bias.[11] In this case estimates are consistent as long as there is no autocorrelation of the error terms. The inclusion of lagged dependent variable and lagged explanatory variables has the effect of reducing the autocorrelation problem. In our regressions we have included lagged dependent and lagged exogenous variables, so autocorrelation should not affect the consistency of our estimates.

[11] Some studies (e.g. Alessandri and Nelson (2012)) deal with this problem by using GMM estimator. However, the asymptotic properties of GMM estimators are derived for large N and small T datasets and may not be applicable to our case (see Attanasio et al. (2000)). Also consistency of the Fixed Effect estimator is not an issue because of the large T. We have therefore used Fixed Effects throughout the paper.
As a robustness check we will include GMM estimates in the Annex.

Another way of determining whether the time-series or the cross-section dimension drives our estimates is to test for Fixed Effects in the main regressions. If they are significant, it would indicate that our findings are mainly driven by the time-series dimension of the panel because individual bank trends are statistically different across banks. In the following section we will test for the presence of Fixed Effects.

5.5. Results

Table 5.2 shows the estimates of regression 5.1 using Fixed Effects (FE) with data until Q2 2007.[12] We initially excluded the financial crisis period from the sample as the relationship between the DA ratio and bank lending may have changed during this period.[13] We will investigate this issue later in the section.

The estimated lags of the DA ratio all have a positive sign and are statistically significant.[14] This may suggest that a bank lending channel exists and that QE may potentially have had an effect on bank lending growth. The long-run coefficient suggests that the effect of an increase in the DA ratio has a positive and statistically significant effect on

[12]DA ratio estimates are similar in magnitude with POLS (not presented here) and FE, but fixed effects are significant and highly correlated with the regressors so POLS estimates are not consistent. Therefore, we will present only FE estimates.

[13]Also the sample used in the regressions is not the full sample of banks because cases with missing observations on any variable are excluded. If the missing cases are systematically related to observed characteristics then there might be sample selection bias, e.g. survivorship bias if only firms that survive are included in the sample and they are systematically different from the excluded failed firms. While sample selection bias is fairly easy to deal with in cross-section, it is more difficult to deal with in dynamic panels of the type used here, so allowing for this is a topic for future research (e.g. using the procedure proposed recently in Semykina and Wooldridge (2013)).

[14]In our preferred specification we use the second and third lags of the DA ratio. To arrive at the preferred specification we first estimated a more general specification (i.e. 4 lags for each variables) and then excluded the highly insignificant variables sequentially to arrive at a more parsimonius specification. However, the main results hold also with specifications with a higher number of lags. The appendix contains a fuller explanation of the selection procedure.

Table 5.2. Deposit asset ratio and total lending

VARIABLES	(1) FE	(2) FE - Small	(3) FE - Large
Lending growth (-1)	-0.114***	-0.120***	-0.0935
	(0.0290)	(0.0324)	(0.0667)
Lending growth (-2)	-0.0176	-0.0224	-0.00506
	(0.0281)	(0.0310)	(0.0780)
Lending growth (-3)	0.0383	0.0346	0.0625
	(0.0285)	(0.0315)	(0.0774)
Lending growth (-4)	-0.0350	-0.0417	0.146*
	(0.0291)	(0.0322)	(0.0768)
ΔCap. ratio (-1)	-0.677***	-0.696***	-0.629
	(0.209)	(0.235)	(0.429)
ΔCap. ratio (-2)	-0.275	-0.346	0.695
	(0.204)	(0.228)	(0.481)
ΔDA ratio (-2)	0.138**	0.161*	0.0655
	(0.0685)	(0.0826)	(0.0843)
ΔDA ratio (-3)	0.132*	0.144*	0.131
	(0.0689)	(0.0825)	(0.0879)
Sectoral demand	2.810	5.969**	-0.137
	(1.844)	(2.879)	(1.311)
Provision ratio (-2)	-1.567**	-1.485*	-2.238*
	(0.720)	(0.822)	(1.348)
Bank size	1.339**	1.599**	0.150
	(0.541)	(0.640)	(0.728)
Macro controls[1]	Yes	Yes	Yes
Constant	-11.20*	-13.29*	2.296
	(6.038)	(6.827)	(9.523)
Observations	1,394	1,128	266
R-squared	0.049	0.057	0.093
Number of banks	50	39	11

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1
(1) GDP growth, Equity returns, Unemployment, Bank rate

lending growth (Table 5.3)[15]. For a 1pp increase in the DA ratio change, quarter over quarter lending growth increases by around 0.24pp in the long-run. In other words, the sum of all the percentage point increases (as time goes to infinity) in bank lending growth is around 0.24pp.

Table 5.3. Long-run coefficients for the total lending regression

	Coef.	S.e.	t	P>t	[95% Conf.	Interval]
ΔDA ratio	0.24	0.10	2.43	0.02	0.05	0.43
ΔCapital ratio	-0.84	0.23	-3.66	0.00	-1.30	-0.39
GDP	1.04	0.73	1.42	0.16	-0.40	2.47
Bank Rate	0.04	0.13	0.31	0.76	-0.21	0.30
Equity returns	0.03	0.02	1.75	0.08	-0.004	0.07
Small banks						
ΔDA ratio	0.27	0.11	2.33	0.02	0.04	0.49
ΔCapital ratio	-0.91	0.25	-3.59	0.00	-1.40	-0.41
GDP	1.59	0.87	1.82	0.07	-0.12	3.30
Bank rate	0.04	0.15	0.29	0.77	-0.26	0.35
Equity returns	0.04	0.02	1.56	0.12	-0.009	0.081
Large banks						
ΔDA ratio	0.22	0.17	1.28	0.20	-0.12	0.56
ΔCapital ratio	0.07	0.65	0.11	0.91	-1.20	1.35
GDP	-1.27	1.14	-1.12	0.27	-3.52	0.97
Bank Rate	-0.18	0.20	-0.90	0.37	-0.58	0.22
Equity returns	0.005	0.029	0.17	0.86	-0.05	0.06

Changes in capital have a strong and negative effect on lending growth in the first lag and in the long run. This is because an increase in capital is costly for the bank (Myers and Majluf (1984)), which has to adjust lending following the negative profit shock. As expected, the provision ratio is negative and statistically significant, as banks reduce their lending when future losses are likely to be higher to build up the capital buffer and absorb

[15] As discussed earlier the long-run coefficient is the sum of the estimates of deposit asset ratio coefficients divided by one minus the sum of the coefficients on lagged lending growth.

eventual losses. Size has a positive and statistically significant effect on lending growth, so that *ceteris paribus* larger banks have a higher lending growth than smaller banks. The sectoral demand variable is not statistically significant, meaning that sectoral differences in lending demand do not explain away our results.

Turning to the macro control variables, real GDP growth and the Bank Rate level are statistically significant for some lags, but they are not statistically significant in the long-run. This is in line with previous research using data on UK banks (e.g. Francis and Osborne (2009), Aiyar et al. (2012)). On the other hand, changes in equity prices (as measured by the FTSE100) have an expected positive and statistically significant coefficient. This suggests that stronger equity prices are associated with stronger lending growth as firms' market leverage decline and is less costly for banks to lend.

5.5.1. Effect of changes in deposit asset ratio on large and small banks

In the previous section we have assumed homogeneity of the DA ratio coefficient, i.e. in equation 5.1 we have assumed that $\gamma_i(L) = \gamma_j(L)$ with $i \neq j$. In this section we will relax this assumption by letting the coefficient vary for small and large banks. Understanding heterogeneity in lending responses is very important for public policy purposes as major banks have a very large share of total lending in the UK banking system.

We have therefore estimated 5.1 for small and large banks using FE (see second and third column of Table 5.2). Large banks' DA ratio coefficients remain positive, but they are not statistically significant anymore. Also the long-run effect remains positive but still not significant (Table 5.3). On the other hand, the DA ratio has a positive and statistically significant effect on small banks, even in the long-run.

However, given that the effects for large and small banks are positive and similar in magnitude it may be that the coefficients are not statistically significant because of lack of observations. We have therefore estimated a regression where every explanatory variable is interacted with a dummy for large banks so that we can test whether the coefficients of large and small bank regressions are statistically different by using an F-test.

The test does not reject equality of coefficients, suggesting that large and small banks may both increase lending growth after an increase in the DA ratio. However, the effect on large banks is somewhat smaller. This could be explained by the fact that large banks can issue non-deposit liabilities more cheaply (because of a better access to capital markets), and changes in deposits can be accommodated by alternative sources of funding. Finding heterogeneity of coefficients for large and small banks is common in the literature and is often used as evidence for the existence of the bank lending channel e.g. Kashyap and Stein (1994, 2000). This is because small banks have limited access to capital markets to raise non-deposit liabilities and a given shock to deposits is therefore met with a sharper reduction in lending than large banks.

5.5.2. Has the relationship changed during the crisis?

One possible criticism for using these estimates to simulate the effects of QE is that the positive relationship we have found held only in periods of relative financial stability. Indeed, other factors during the current financial crisis may have reduced the ability of banks to increase lending as their balance sheet became more liquid. For example, large losses during the financial crisis have reduced bank capital buffers (i.e. the amount of capital above the minimum capital requirements) constraining new lending even when deposits (and cash) are increasing due to QE. However, one of the advantages of using panel data is that we can control for changes in capital ratios on a bank-by-bank basis, so that our estimates are less likely to be affected by the effects of the banking crisis. Moreover, our dataset includes events of financial instability in the early 1990s which affects our estimates.

A simple way to investigate whether the relationship changed during the crisis is to run a FE regression over the full sample and check if the positive relationship still holds. More formally, we can include a 'crisis' dummy taking value one from 2007 Q3 which marks the beginning of the financial crisis in the UK when Northern Rock received liquidity support from the Bank of England. We can then test whether the DA ratio had a different effect during the crisis by including interaction variables between the deposit ratio and the crisis dummy. Table 5.4 (first three columns) compares our pre-crisis estimates with estimates for the whole sample and those using the additional 'crisis' dummy and interaction variables.

DA ratio coefficients and their significance are little changed when we consider the full sample. But then this does not tell us anything specific about the effects of QE during the financial crisis. If the effect of QE changed during the financial crisis we would expect the interaction coefficients to be jointly statistically significant (column 3). The interaction terms are negative, which may indicate smaller DA coefficients, but the test for joint significance does not reject a zero effect indicating that the relationship may have remained stable even during the financial crisis.

Above we have tested that the deposit ratio coefficients were not statistically different during the crisis. We can also test for a structural break during the financial crisis (i.e.

Table 5.4. Lending and deposit asset ratio during the crisis period

VARIABLES	Until Q2 2007	Whole sample	Whole sample	Whole sample
ΔDA ratio (-2)	0.138**	0.123**	0.157**	-0.120
	(0.0685)	(0.0617)	(0.0667)	(0.0790)
ΔDA ratio (-3)	0.132*	0.127**	0.145**	-0.137*
	(0.0689)	(0.0625)	(0.0671)	(0.0785)
Crisis			-0.280	
			(0.729)	
Crisis*ΔDA ratio (-2)			-0.254	
			(0.176)	
Crisis*ΔDA ratio (-3)			-0.179	
			(0.177)	
High capital				-0.360
				(0.595)
High cap.*ΔDA ratio (-2)				0.595***
				(0.128)
High cap.*ΔDA ratio (-3)				0.676***
				(0.129)

all the coefficients are statistically different) using a Chow test. The test does not reject the null of no structural break. However, a variance ratio test excludes that variances are the same in the two sub-periods and therefore the Chow test is not applicable (this is because the Chow test assumes equality of variances). This means that we cannot exclude with certainty a structural break, even though the deposit ratio estimates did not change during the crisis period. On the other hand, the interaction variables are negative and their insignificance may also be driven by the lack of 'crisis' data.

An alternative approach would be to investigate the relationship between the DA ratio and capital *levels* during the whole sample and infer from this relationship what might have happened during the crisis given the large capital losses experienced by UK banks during the financial crisis. If the effect of the DA ratio on lending changes with capital we would expect the interaction terms to be statistically significant, meaning that the effect of DA ratio may have changed during the crisis. The 'capital channel' literature suggests that banks with a higher capital ratio may react more to a given monetary policy shock (Van den Heuvel (2002)).

We have therefore run our baseline regression adding a dummy taking value one for banks with a capital ratio higher than the sample average (around 15%) (Table 5.4, last column). The interaction terms are positive and highly statistically significant, suggesting that our overall estimates are driven by institutions with above average capital ratios. This is because banks with a higher capital ratio can increase lending more than lower capitalised banks following an increase in deposits in line with the existence of a 'bank capital' channel. This is because lower capitalised banks may not be able to increase lending as they may breach minimum capital requirements if they do so.

Even though this finding does not give a definitive answer on the effect of the DA ratio during the crisis (because the relationship between capital and DA ratio may have changed during the crisis) these results may suggest that the effect of QE during the banking crisis might have been somewhat lower given capital losses experienced by few major banks.

However, a stronger effect from better capitalised may have offset lower lending from lower capitalised banks during the crisis. We can therefore use these results only as an indication on what may have happened to the magnitude of the effect and we will be able to reach a definitive answer on whether the relationship between lending and deposits remained unaltered during the crisis period only with more observations during the crisis period.

5.5.3. Endogeneity of the deposit asset ratio

Until now we have assumed exogeneity of the DA ratio, i.e. it is not correlated with the error term in equation 5.1. In this case a change in DA ratio can be interpreted to have a causal effect on lending growth. However, banks may collect deposits only after they have identified lending opportunities, which we call the 'investment opportunities' hypothesis. In this case deposits will be positively correlated with lending, even though more deposits are not *causing* the increase in lending. In other words, we may be facing an endogeneity problem and our estimated effect of QE on lending will be biased and inconsistent.

However, if we assume that economic growth is a good proxy for investment opportunities (i.e. stronger economic growth is related to more investment opportunities) we can then test the hypothesis above by running a regression of DA ratio changes on a set of bank specific and macroeconomic variables in line with specification 5.1.

This can be justified by the fact that the DA ratio is both related to bank specific factors (e.g. certain banks will have a structurally higher DA ratio) and to macroeconomic factors (e.g. during a boom DA ratio declines as banks use alternative forms of financing to expand their balance sheet). If better investment opportunities lead banks to seek deposits to finance them, we would expect economic growth to affect changes in DA ratio. Table 5.5 shows the coefficients for the deposit growth regression. Macroeconomic variables proxying investment opportunities (e.g. GDP growth, changes in stock market prices and Bank of England Base Rate) are all statistically insignificant.[16] This would suggest that

[16]F-tests for joint significance shows that these variables can be removed altogether from the main specification without much loss of explanatory power.

Table 5.5. DA ratio and investment opportunities

VARIABLES	(1) ΔDA ratio	(2) ΔDA ratio	(3) ΔDA ratio	(4) ΔDA ratio
ΔDA ratio (-1)	-0.282***	-0.285***	-0.281***	-0.280***
ΔDA ratio (-2)	-0.0482*	-0.0446*	-0.0413	-0.0410
ΔDA ratio (-3)	-0.0858***	-0.0874***	-0.0862***	-0.0853***
ΔDA ratio (-4)	0.121***	0.123***	0.123***	0.123***
ΔCap. ratio (-1)	0.381***	0.381***	0.379***	0.374***
ΔCap. ratio (-2)	0.209**	0.207**	0.203**	0.208**
ΔCap. ratio (-3)	-0.0473	-0.0466	-0.0445	-0.0465
ΔCap. ratio (-4)	0.216**	0.223***	0.223***	0.223***
Crisis	0.905**	0.958***	0.970***	1.033***
Provision ratio (-2)	0.183	0.182	0.234	0.244
Bank size	-0.0683	-0.0349	-0.261	-0.275
Equity returns (-1)	-0.0173*			
Equity returns (-2)	0.0116			
Equity returns (-3)	-0.000581			
Equity returns (-4)	0.0118			
Unemployment	-0.152*	-0.148*	-0.134*	-0.139*
GDP growth (-1)	-0.114	-0.0981	-0.126	
GDP growth (-2)	-0.0215	-0.00904	-0.0711	
GDP growth (-3)	0.0161	0.155	0.195	
GDP growth (-4)	-0.0371	-0.108	-0.0585	
BoE rate (-1)	0.0829	0.0788		
BoE rate (-2)	0.129	0.199		
BoE rate (-3)	-0.177	-0.273		
BoE rate (-4)	0.0958	0.137		
Constant	0.652	0.192	3.029	3.150
Observations	1,729	1,729	1,729	1,729
R-squared	0.127	0.124	0.120	0.120
Number of banks	52	52	52	52

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

investment opportunities do not drive deposit growth and therefore endogeneity issues are likely to be limited.

5.6. Estimating the impact of QE on bank lending

Now that we have estimated the effects of changes in the deposit ratio on lending growth, we can estimate the impact of QE on bank lending in the UK.[17] To do so we first need to identify the likely change of deposits in the UK financial system following QE. A possible approach would be to assume that this increase is equal to the £200bn of gilts purchased during the QE programme. However, Bridges and Thomas (2012) consider a three factors that may offset the increase in deposits due to QE.

First, the Bank of England may have purchased gilts from the non-UK financial sector or UK banking sector. In this case the increase in deposits may be lower than total assets purchased because the increase in deposits will materialise in the country of residence of the selling financial institution (e.g. seller is non-UK financial company) or there is a change in the composition of bank's balance sheet without an increase in deposits (e.g. seller is a UK bank). Observing patterns of gilts held by UK banks during the period of QE, the authors conclude that this offsetting channel may not be significant.

Second, QE-induced lower yields and asset prices may have led to an increase in UK banks' equity and/or long-term debt issuance. The authors argue that UK banks' deposits will decline by the amount of the increase in equity or long-term debt if this issuance is purchased by non-banks. They then make a number of assumptions to estimate a £60bn offsetting effect of this channel. One potential problem with this approach is that issuance of bank equity and/or long term bank debt may not necessarily lead to a reduction of deposits. This is indeed a function of how the purchases of these instruments are funded. For example, if non-bank financial institutions buy bank equity funded by a bank loan,

[17] For ease of tractability we will not consider the relationship between capital and DA ratio in this section and we will use estimates using pre-crisis data.

both bank and non-bank balance sheet will expand and deposits will remain unchanged. Of course, this factor is very difficult to quantify but adds another degree of uncertainty to Bridges and Thomas (2012) estimates.

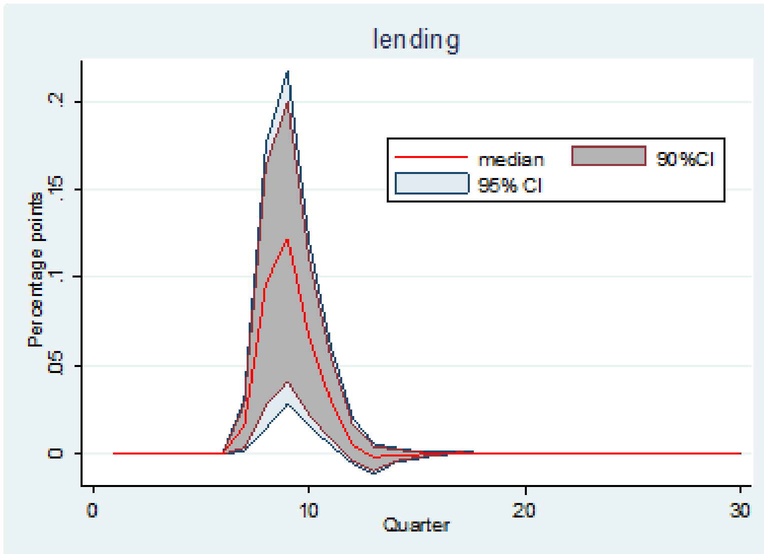
Table 5.6. Asset purchases and effect on deposit over asset ratio

Date	Purchases (£bn)	Deposits (£bn)	Assets (£bn)	Ratio (per cent)	Change (pp)
Q4 2008	0.0	3300.9	5455.3	60.5	
Q1 2009	15.5	3316.3	5470.8	60.6	0.1
Q2 2009	84.4	3400.7	5555.2	61.2	0.6
Q3 2009	56.1	3456.8	5611.3	61.6	0.4
Q4 2009	32.1	3488.9	5643.4	61.8	0.2
Q1 2010	9.6	3498.5	5653.0	61.9	0.1

Third, some of the additional deposits created may have been absorbed because PNFCs have used proceeds from the issuance of equity or debt to repay bank loans during the crisis in order to deleverage or disintermediate. The authors then point to the decline in bank lending to PNFC, the increase in the issuance of corporate equity and debt and the increase in net loan repayments as an indication of corporates substituting away from bank finance. Assuming that all the extra PNFC issuance compared with the 1990s recession was attributable to QE and that *all* the proceeds were used to repay bank loans, the authors suggest an offsetting effect of £16bn. However, the assumption that all of this amount has been used to repay bank loans is quite restrictive. According to Dealogic data, UK corporates have used around 25% of the proceeds of their corporate bond and equity issuance to repay corporate bonds *and* bank loans. This suggests that Bridges and Thomas (2012) may have overestimated the true offsetting effect through this channel.

Given the difficulties in estimating accurately the effect of QE on broad money we have therefore estimated the impulse response functions based on the simplifying assumption

Figure 5.3. Bank lending following a £200bn increase in deposits

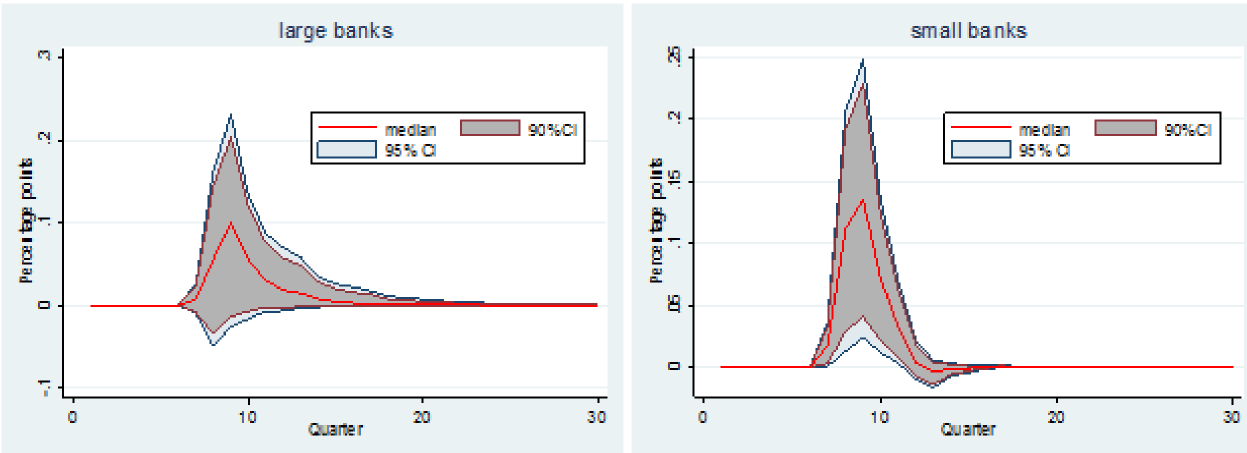


that £200bn of QE increased deposits by the same amount (i.e. there is a one for one relationship between asset purchased and new deposits created). Our estimates are therefore an upper bound of the likely effect on bank lending as some of the new deposits created will have been 'absorbed' by the channels described above.

We have based these simulations on the actual purchases of gilts in 2009 and 2010 by the Bank of England and estimated the impact on the DA ratio for the average bank using our dataset (Table 5.6). We have also assumed that total assets increase in line with the increase in deposits. For example, after the first £15bn asset purchase, £15bn of new deposits are created in the banking system and total assets change by the same amount. This means that the DA ratio increased by around 0.1pp.

We then use these estimated changes in the DA ratio as a shock in our simulation, with the first asset purchase materialising in period 5. Figure 5.3 shows the simulation for total lending. The effect of QE peaks around four quarters (median effect around 0.1pp

Figure 5.4. Bank lending for large and small banks following a £200bn increase in deposits



on q/q lending or 0.4pp q/q annualised) after the first purchases and the effect fades away around seven quarters after the first asset purchase.

The impact on lending growth is statistically different from zero. In the long-run, the cumulative effect on lending growth for our estimated change in deposits (approximately the area under the red line) is around 0.3pp for q/q lending growth or 1.2pp for q/q annualised lending growth.[18]

As discussed in Section 5, the significance of DA ratio on bank lending differs for large and small banks. Figure 5.4 shows the simulations for large and small banks using the same estimates as in Table 5.2. Despite being positive, the large banks' change in lending is not statistically different from zero (the zero line is within the confidence intervals). On the other hand, small banks' lending impulse response is similar in shape to the pooled regression in Figure 5.3, even though the peak impact of changes in the DA ratio is

[18]This is derived by using the long-term coefficients in Table 2. For a 1pp increase in the DA ratio increases total lending growth by around 0.24pp in the long run. If we then multiply this amount for the cumulated impact of QE on DA ratio (i.e. 1.4) we obtain 0.3pp.

approximately three times stronger (the peak effect for small banks reaches around 0.3pp q/q after four quarters against 0.1pp q/q in the pooled case). However, given that we cannot reject equality of coefficients for large and small banks we can assume that the effect is positive also for large banks even though somewhat smaller.

5.7. Conclusions

In this paper we investigate the potential effects of QE on bank lending growth using a new and non-publicly available panel dataset on UK banks. So far, the vast majority of research on QE has focussed on the impact on economic growth and financial markets using aggregate time-series data, while the effect of QE on bank lending has been largely neglected. This is because policymakers expected QE to affect demand mainly through financial markets (e.g. expectations and portfolio rebalancing effects), while the effect on bank lending was expected to be small because of banks' incentives to delever during the banking crisis. To our knowledge, this is the first paper to try to quantify the effect of QE on bank lending in the UK using a panel dataset. Our approach allows us to control for bank specific factors (e.g. shocks to capital) and to test for heterogeneity in the effects of QE on bank lending.

We found that QE may have led to small but statistically significant increases in bank lending. The effect on bank lending is heterogeneous, as small banks have increased lending more than large banks, consistent with economic theory. However, we also found evidence that the effect of QE on bank lending may have been smaller than initially estimated because of lower levels of capital during the crisis.

Appendix

5.A. Appendix

5.A.1. The appropriate number of lags: from general to specific

There is no 'golden rule' to choose the correct specification and in particular the appropriate number of lags (see Verbeek (2012) for a summary of all possible approaches). The approach we have used is to start with a General Unrestricted Model (GUM) and then reduce it in size using tests for joint significance. The intuition here is that we would like to have a relatively parsimonious model so that our coefficients can be interpreted more easily.

Table 5.A.1 show all the steps we have taken to reach the final specification. We have started by estimating a very general specification including 4 lags of the bank specific controls and macro variables.

As a first step, we have dropped the last two lags of the provision ratio using an F-test for joint significance. Second we have noticed that the contemporaneous GDP and Bank rate variables were highly insignificant, so we dropped both. We have left the remaining four lags for each variable.

Third we have dropped the last two lags of the capital ratio as the probability of them being jointly equal to zero was around 30 per cent so that dropping them changed very little in terms of cumulative effect on lending growth. In the fourth and fifth step we have dropped the first and last lags of the DA ratio as they were both highly insignificant.

Table 5.A.1. From a general to the final specification

	lag no. general spec.	1st test	2nd test	3rd test	4th test	5th test
Total lending	4	4	4	4	4	4
Capital ratio	4	4	4	2	2	2
Deposit ratio	4	4	4	4	3	2
Provision ratio	4	2	2	2	2	2
GDP	4 + cont	4 + cont	4	4	4	4
Bank rate	4 + cont	4 + cont	4	4	4	4
Prob>F (joint sign.)		0.6327		0.279		
p-value (ind. sign.)			0.743, 0.919		0.785	0.301

5.A.2. Assumption on deposit over asset aggregation to run impulse response functions

Note that in the impulse responses we use changes in the deposit asset ratio derived at an aggregate level. These changes are then used in the impulse responses to estimate average bank changes in lending. But this is not necessarily the same as estimating deposit asset ratio changes for individual banks and then use the averages of these changes in the impulse responses. We cannot proceed with the latter approach as we do not know the distribution of QE-created deposits across banks. We therefore assume that:

$$\frac{\sum D_{it}}{\sum A_{it}} - \frac{\sum D_{it-1}}{\sum A_{it-1}} = \frac{\sum(\frac{D_{it}}{A_{it}} - \frac{D_{it-1}}{A_{it-1}})}{n} \tag{5.1}$$

Table 5.A.2. Deposit ratio and lending with robust standard errors

VARIABLES	(1) FE	(2) FE - small	(3) FE - large
Lending growth (-1)	-0.117**	-0.123**	-0.0984
	(0.0452)	(0.0475)	(0.145)
Lending growth (-2)	-0.0193	-0.0237	-0.00804
	(0.0583)	(0.0614)	(0.0972)
Lending growth (-3)	0.0431	0.0394	0.0623
	(0.0587)	(0.0603)	(0.0825)
Lending growth (-4)	-0.0399	-0.0472	0.148**
	(0.0490)	(0.0510)	(0.0545)
ΔCap. ratio (-1)	-0.753**	-0.773**	-0.628
	(0.291)	(0.310)	(0.756)
ΔCap. ratio (-2)	-0.259	-0.329	0.697
	(0.299)	(0.317)	(0.882)
ΔDAratio (-2)	0.128	0.142	0.0755**
	(0.132)	(0.161)	(0.0326)
ΔDAratio (-3)	0.144	0.157	0.136**
	(0.126)	(0.152)	(0.0512)
Sectoral demand	2.790	5.952**	-0.114
	(1.819)	(2.630)	(0.424)
Provision ratio (-2)	-1.703	-1.628	-2.254***
	(1.896)	(2.124)	(0.503)
Bank size	1.280	1.498	0.214
	(1.098)	(1.259)	(0.923)
Macro variables	Yes	Yes	Yes
Constant	-10.42	-12.09	1.451
	(12.13)	(13.25)	(12.86)
Observations	1,371	1,110	261
R-squared	0.053	0.060	0.093
Number of banks	50	39	11

Robust standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

or in other words that the general change of deposit asset ratio is equal to the average individual bank change of the ratio. With a bit of algebra we can see that this is equal to:

(5.2) $$\frac{\sum D_{it}}{\sum A_{it}} - \frac{1}{n}(\sum \frac{D_{it}}{A_{it}}) = \frac{\sum D_{it-1}}{\sum A_{it-1}} - \frac{1}{n}(\sum \frac{D_{it-1}}{A_{it-1}}).$$

This expression is the restriction that we are applying to individual bank changes in deposit asset ratio. The interpretation is that the deviation of the aggregate change from the bank average changes needs to be constant across time.

5.A.3. Comparing FE with GMM estimates

In Table 5.A.3 we have estimated specification 5.1 using Arellano-Bond difference GMM estimator. The presence of lagged dependent variables may potentially lead to a bias that may affect our estimates. One possible approach is to address the endogeneity of lagged dependent variables by using the GMM estimator with lags of the levels of the dependent variables as instruments. Our results suggest that the difference between FE and GMM is not large and the log run coefficient remains positive, even though smaller than FE estimates (Table 5.A.4). Attanasio et al. (2000) show that when the number of time periods exceeds 30 (i.e. our case), the bias created by the FE estimator is more than offset by its greater precision compared to GMM estimators. And Judson and Owen run a Montecarlo simulation to show that, if T is greater than 30, FE fares better than GMM in terms of efficiency, bias and error. For these reasons FE remains our favourite estimation method.

Table 5.A.3. Deposit asset ratio and total lending - a comparison between FE and GMM

VARIABLES	(1) FE	(2) GMM
Lending growth (-1)	-0.114***	-0.339***
	(0.0290)	(0.0369)
Lending growth (-2)	-0.0176	-0.213***
	(0.0281)	(0.0385)
Lending growth (-3)	0.0383	-0.0345
	(0.0285)	(0.0327)
Lending growth (-4)	-0.0350	-0.0730**
	(0.0291)	(0.0304)
ΔCap. ratio (-1)	-0.677***	-0.482**
	(0.209)	(0.208)
ΔCap. ratio (-2)	-0.275	-0.337*
	(0.204)	(0.196)
ΔDA ratio (-2)	0.138**	0.0645
	(0.0685)	(0.0710)
ΔDA ratio (-3)	0.132*	0.154**
	(0.0689)	(0.0729)
Sectoral demand	2.810	2.931*
	(1.844)	(1.721)
Provision ratio (-2)	-1.567**	-3.572***
	(0.720)	(1.151)
Bank size	1.339**	0.585
	(0.541)	(1.654)
Macro controls[1]	Yes	Yes
Constant	-11.20*	n.a.
	(6.038)	
Observations	1,394	1,312
R-squared	0.049	n.a.
Number of banks	50	50

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1
(1) GDP growth, Equity returns, Unemployment, Bank rate

Table 5.A.4. Comparing FE and GMM long run coefficients

	Coef.	Std. Err.	t	[95% Conf.	Interval]
ΔDA ratio (FE)	0.24	0.10	2.43	0.05	0.43
ΔDA ratio (GMM)	0.13	0.07	1.77	-0.01	0.27

5.A.4. Deposit ratio and lending with robust standard errors

A modified Wald test (we have used 'xttest3' command in Stata which is a modified Wald test as in Greene (2000)) on equation 5.1 rejects the hypothesis that the variances of the groups are the same, i.e. it suggests that there is group-wise heteroskedasticity. The formula has been modified to allow for unbalanced panels. In terms of small sample properties, simulations of the test statistic have shown that its power is very low in the context of fixed effects with "large N, small T" panels. In that circumstance, the test should be used with caution. A test for serial correlation as in Wooldridge (2000) rejects the hypothesis of no serial correlation (we have used 'xtserial' command in Stata). However, this test is constructed for large N small T, and therefore may not be applicable to our dataset. We are not aware of alternative serial correlation tests for large T, small N case.

However, a visual inspection of bank by bank predicted errors seems to suggest that there is limited serial correlation within groups. Wooldridge (2000) shows that the robust variance-covariance matrix is valid with group-wise heteroskedasticity or serial correlation within individual panels, provided that T is small relative to N. The author adds that OLS standard errors 'may be better behaved under assumptions of homoskedasticity if N is not very large relative to T'.

There is not much literature deriving asymptotic properties of robust variance-covariance matrix when T is large and N small. Using Montecarlo Simulations, Kezdi (2004) shows that the robust estimator of the variance-covariance matrix does not get biased or significantly more dispersed as T increases. Hansen (2006) derives the asymptotic properties of the robust covariance matrix as T goes to infinity and N fixed, and shows that the robust estimator is not consistent but it does have a limiting distribution. In this case the t-statistic is not asymptotically normal but converges in distribution to a random variable proportional to a t (n-1) distribution. Hansen (2006) suggests to use this distribution to construct confidence intervals and tests when robust covariance matrix is used.

However, these papers do not consider the case of unbalanced panels. Given that our panel is unbalanced this may raise further problems in using robust variance-covariance matrix. Again here there is no strong evidence, but Austin Nichols and Mark Schaffer suggest in a presentation (http://repec.org/usug2007/crse.pdf) that with a small number of clusters, or very unbalanced cluster sizes 'the cure (of using robust standard error) can be worse than the disease'. We have therefore used non robust variance covariance matrixes in this paper.

5.A.5. Chow tests for structural breaks

Table 5.A.5 presents structural break tests for large/small banks and the crisis period. The upper panel shows that we cannot reject equality of coefficients for large and small banks, i.e. large and small banks react to changes in the deposit ratio in a similar way. The lower panel shows that the null hypothesis of no structural breaks is not rejected, i.e. there is no structural break during the crisis.

Table 5.A.5. Test for large and small banks and crisis structural breaks

Test	Statistic	Prob>F
Large banks coefficients same as small banks	F(19, 1304) = 0.53	0.9507
No crisis structural break	F(19, 1415) = 1.13	0.3133

5.A.6. F-tests for joint significance for macroeconomic variables

In table 5.A.6 we report F-tests for joint significance of macroeconomic variables (that we use as proxies of investment opportunities) in the auxiliary deposit regression. These tests show that these variables can be removed from the auxiliary regression as they are jointly not statistically significant. This suggests that banks do not change their deposit ratios ahead of future investment opportunities.

Table 5.A.6. F-test for joint significance in the DA ratio regression

Test	Statistic	Prob>F
FTSE	F(4, 1653) = 1.55	0.1849
GDP	F(4, 1661) = 0.30	0.875
Bank rate	F(4, 1657) = 1.54	0.1884

CHAPTER 6

The Transmission Mechanism of Time-Varying Capital Requirements

6.1. Introduction

As a policy response to the financial crisis, the UK government has established the Financial Policy Committee (FPC), the first example of a macroprudential regulator. [1] The stated objectives of the FPC are to reduce systemic risk through two channels: increasing the resilience of the financial system by forcing banking institutions to hold more capital, and dampening the credit cycle by reducing lending to the real economy during an expansionary credit phase.[2] The complete toolkit available to the FPC is still uncertain, but time-series changes in capital requirements are likely to be one of the main policy instruments.[3]

Economic theory and empirical evidence have generally established that there is a negative relationship between changes in regulatory capital ratios and credit supply (VanHoose (2008)). However, there are still uncertainties on how changes in capital requirements will affect the banking system and the real economy. In particular, how will the

[1]The interim FPC became operative in June 2011. The record of the second FPC meeting can be found at http://www.bankofengland.co.uk/publications/records/fpc/pdf/2011/record1110.pdf

[2]See for example P. Tucker speech 'Macroprudential policy: building financial stability institutions' for the remit of the FPC, http://www.bankofengland.co.uk/publications/speeches/2011/speech492.pdf

[3]The interim FPC agreed to advise HM Treasury that the statutory FPC should have powers of direction over the countercyclical capital buffer, sectoral capital requirements and a leverage ratio. http://www.bankofengland.co.uk/financialstability/Documents/fpc/statement120323.pdf

transmission mechanism work? What is the effect of a change in capital requirements on lending growth? And will banks change the composition of their lending as well? This chapter will try to answer these and related questions from an empirical perspective using a new and non-publicly available panel dataset of banks operating in the UK.

The existence of the transmission mechanism of capital requirements hinges on the failure of the Modigliani-Miller (M-M) theorem (1958). In the M-M world shocks to capital will not have any impact on bank lending decisions. But in reality several frictions make changes in capital non-neutral from the bank perspective, so that changes in capital requirements are likely to affect bank lending growth. The frictions often cited in the literature are the tax deductibility of debt, asymmetric information problems (Myers and Majluf (1984)) and debt-overhang problems (Myers (1977)).

The non-neutrality of capital is also well documented in the empirical literature that uses panel datasets. Bernanke and Lown (1991) and Peek and Rosengren (1997) are early examples of this. And more recent empirical literature confirmed that shocks to capital (or changes in capital requirements) affect lending growth (e.g. Francis and Osborne (2010) for the UK and Berrospide and Edge (2010) for the US).

In contrast to the large majority of the research investigating the relationship between capital (or capital requirements) and lending, our dataset contains regulatory (and non-publicly available) information on individual capital requirements that vary over time, the so called ‘trigger’ capital requirements. These requirements are set above the regulatory minimum and regulatory action is taken if these requirements are breached.

The use of these capital requirements provides us with a macroprudential tool proxy allowing us to estimate the effectiveness of these tools on bank lending growth.[4] For example, Ayiar et al. (2012) have used a UK bank panel dataset containing trigger capital requirements and showed that increases in capital requirements leads to a decline in bank lending growth.

The contribution of this paper is to estimate a dynamic model of bank lending growth to quantify both short and long-run effects of changes in capital requirements on bank lending growth. We also estimate a capital equation which helps us understand better how the transmission mechanism of capital requirements works. To do so, we employ a newly constructed and non-publicly available dataset with observations since 1989 which allows us to capture two full business cycles.

We find that an increase in trigger capital requirements reduces bank lending growth. The effect of the increase in capital requirements is transmitted through increases of actual holdings of capital. Capital requirements are therefore binding, a necessary conditions for the transmission mechanism to work. The effect of capital requirements on lending is quite large and highly statistically significant. But the effect is not homogenous and large and small banks react differently to an increase in capital requirements. In particular, large banks seem insensitive to a change in regulatory policy, while small banks react to it quite strongly. This could have potentially important implications as few large banks constitute a conspicuous slice of the lending market. We also find that banks not only reduce the volume of lending, but de-risk their balance sheet in the short term in an effort

[4]It is difficult to determine whether the underlying rationale for changes in capital requirements were microprudential or macroprudential in nature. Here we assume that changes in time series capital requirements before the establishment of the macroprudential regulator is a good proxy of future macroprudential changes in capital requirements.

to reduce their risk weighted assets. The macroprudential authority should therefore take into account that changes in capital requirements are likely to affect bank capital ratios, the volume and composition of lending.

In Section 6.2 we outline a possible transmission mechanism of capital requirements on bank capital and bank lending while Section 6.3 describes briefly the dataset and present some summary statistics. In Section 6.4 we look at the relationship between capital requirements, capital and bank lending. Section 6.5 concludes.

6.2. A possible transmission mechanism of capital requirements

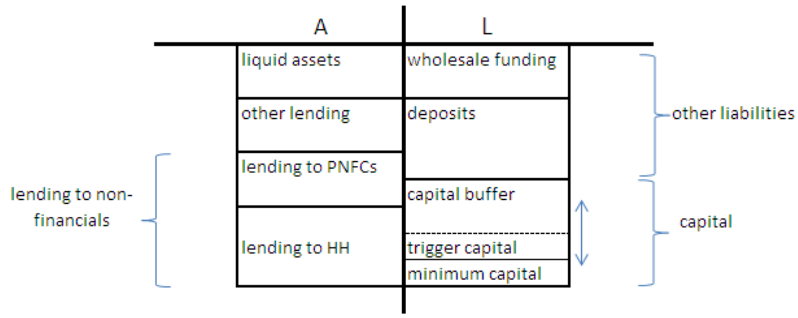
In a Modigliani-Miller (M-M) framework the structure of bank capital does not have an impact on the cost of capital. This means that an increase in capital requirements will not affect banks' funding costs and therefore lending to the real economy is likely to remain unchanged.[5]

However, there may be various frictions so that a change in capital requirements (and therefore capital ratios) is likely to have a real effect. The most often cited friction is the deductibility of debt interest payments, which will lead to an increase in bank's funding costs when capital requirements (or trigger capital requirements) are raised (Figure 6.1). In this case the bank may try to pass on higher funding costs to borrowers by increasing lending spreads or by reducing the volume of new lending.

In a M-M world, following an increase in capital requirements, we would expect banks to raise new equity to increase the capital (K) over risk weighted assets (RWA) ratio.

[5]We assume that there is a relationship between capital and regulatory capital requirements, i.e. capital requirements are binding. Banks try to maintain a constant buffer above the minimum, so that an increase in reglatory capital leads to an increase in the capital ratio. This is supported by empirical evidence in the UK, see for example Alfon et al (2005) and Francis and Osborne (2009), Ediz et al (1998)

Figure 6.1. A stylised bank balance sheet



Alternatively, banks could cut dividends or lower staff pay to increase their retained profits and accumulate more capital. Absent any frictions, cutting RWA would not be rational as banks are profit maximizing agents and it would reduce their expected profitability (and therefore their value).

The first option facing the bank - raising fresh equity - would increase the capital ratio (K/RWA) via the numerator. But the literature has shown that raising equity voluntarily may signal to the market that the issuer is 'bad' (see Myers and Majluf (1984)), the so called 'adverse selection' problem. This is because equity pays out only in good states of the world. In this case raising fresh equity may increase further funding costs. The importance of this friction is likely to be limited in a macroprudential policy regime as the regulator will ask all banks to raise capital at the same time. In this case raising fresh capital may not reveal additional information about the health of the bank.

The second option facing the bank – reduce dividend payments – would increase retained profits and therefore the ability of the bank to accumulate capital. However, in a world with competing banks, the level of dividends and staff pay may be sticky (for example because of a collective action problem). Deviating from what the other competitors are doing may lead to lower equity prices and staff being hired in higher paying institutions.

An increase in funding costs (e.g. because of equity issuance) will lead banks to increase the interest charged to customers. But banks usually borrow short to lend long, i.e. the loan book has usually a longer average maturity than its liabilities and it will not be re-priceble at least in the short term. This will lengthen the adjustment process to the new capital requirements. This is because profits will be affected in the short term and the capacity of the bank to reach the new capital ratio via retained profits will be reduced (i.e. the adjustment happens via changes in volume). The more difficult the re-pricing, the higher the adjustment via lower RWA. Alessandri and Nelson (2012) provide evidence on the existence of repricing frictions in banking.

Another frequently cited reason for why capital may be costly is the debt overhang problem (Myers (1977)). In this case banks with weak balance sheets will be reluctant to invest in new projects as the possible payoffs will be absorbed by senior creditors. This is because shareholders are the first in line to absorb losses. Shareholders' interest will therefore be to rebuild the capital ratio by reducing assets rather than increasing capital.

French et al. (2010) argue that debt financing is a disciplining device to solve the so called 'free cash flow' problem, and increases in the capital ratio may therefore increase banks' risk taking incentives. This may lead in turn to an increase in the cost of capital. However, though appealing on a theoretical basis, it seems that financial crises are usually preceded by large increases in leverage. The claim that debt is a disciplining device seems therefore not supported by empirical evidence.

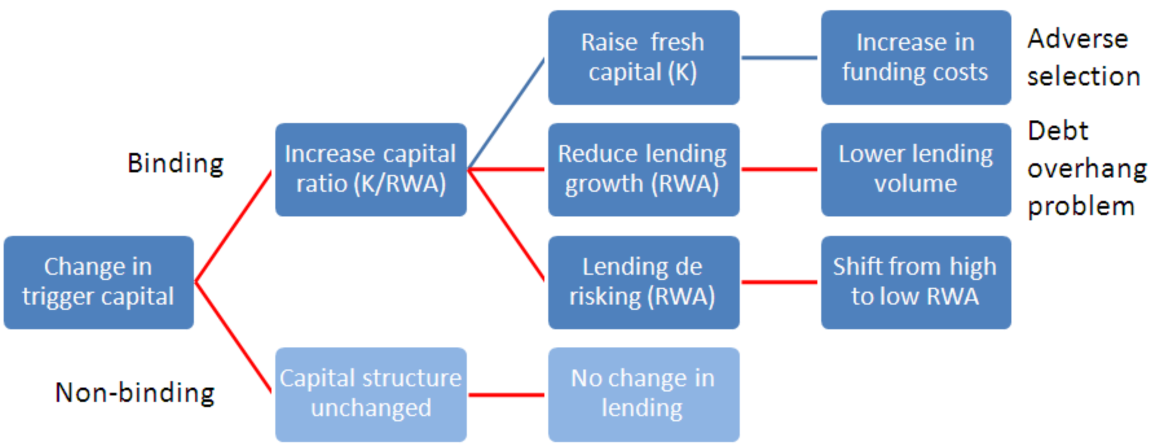
On the other spectrum of capital theory, Admati et al (2011) argue that capital is not costly. Their analysis consists in an examination of all the frictions highlighted above and reaching the conclusion that increasing bank capital is not socially expensive, as it would deliver larger social benefits. However, the vast majority of theoretical and empirical evidence seems to suggest that capital is expensive, at least in the short term.

The market imperfections and frictions highlighted above will make more likely that banks will choose to adjust to an increase in capital requirements by changing their RWA, therefore affecting lending and the real economy. This adjustment can be made in three ways (Figure 6.2). First, banks can reduce lending growth by cutting on new lending. Second, banks can lower the risk profile of the loans without reducing the volume of loans, i.e. reduce those loans that have a higher risk weight (therefore reducing RWA). Third, they can dispose of parts of their portfolio and increase their equity capital. This chapter considers the first two channels.[6]

In addition, a change in capital requirements may affect lending via the expectations channel. In monetary policy, expectations of changes in interest rates affect market interest rates, which in turn affect economic activity. Expectations of changes in capital requirements operate in a similar way. If banks believe that an increase in capital requirements is forthcoming, they may adjust the level of capital (K) or risk-weighted assets (RWA) to avoid sharper adjustments after the announcement (e.g. because sharp adjustments of capital are costly). However, this channel will become more important after eventual changes of FPC macroprudential policy stance, e.g. by increasing or lowering

[6]Ultimately these adjustments will have an effect on the real economy if we believe that lending activity is special in the sense that corporates are not able to perfectly substitute bank lending with market debt (see Bernanke and Lown (1991)). We will not analyse this aspect of the transmission mechanism in this paper.

Figure 6.2. Transmission mechanism of capital requirements



capital requirements. We will not therefore consider the expectations channel in this paper and leave this analysis to future research.

6.3. Description of the data

This new and non publicly available panel dataset includes quarterly balance sheet and income statement data of 30 different financial institutions active in the lending market operating in the UK from 1989 until end 2010. The panel is unbalanced as the time series is discontinued after mergers and failures - banks are observed for a minimum of 9 periods and a maximum of 92 periods.

The sample includes UK-owned banks, foreign-owned banks (around 60% of the sample), building societies (around 10% of the sample) and non-bank financial institutions (around 17% of the sample). We have considered financial entities on a consolidated level, as we assume that lending and capital decisions are taken on a group-level basis (Houston et al. (1997)). Considering a lower level of consolidation would instead assume that capital cannot be transferred within the group. Given that this is a strong assumption, we believe this dataset better reflects real capital-lending dynamics in a complex banking group. An unconsolidated level approach is instead followed by other related research, e.g. Francis and Osborne (2010).

Our dataset includes Bank of England information on bank's balance sheet and income statements (e.g. bank lending and profits) and FSA data on regulatory capital requirements. In particular, the FSA reports regulatory capital held by each bank, and a time-varying individual minimum capital *requirements*, the so called 'trigger' capital requirements (capital requirements from now on). These additional requirements were set by UK regulators starting in 1989 as the regulators felt that Basel I Accord did not take into account a wide range of risks (e.g. interest rate risks, reputational and operational risks) that may affect firms' probability of default (Richardson and Stephenson, 2000). Capital requirements are usually set above the minimum regulatory capital and are mainly based on general market conditions, risk management practice and strength of individual banks' controls (FSA (2001), Francis and Osborne (2009)). If a bank breaches this 'trigger' level, regulatory action is taken. The capital requirements are set by the FSA on a bank by bank basis and vary over time (they are usually reviewed every 18-36 months) which allows us to use it as a proxy for a macroprudential instrument.

Table 6.1. Summary statistics

Variable	Obs	Mean, GBPmn	Std. Dev.	Min	Max
Total lending	4016	15909.94	37484.34	0	311344.9
Household lending	4019	11221.95	27198.97	0	237846.5
PNFC lending	4045	4654.021	12289.17	0	121783.7
Secured lending to households	3920	9048.897	23040.73	0	218855.8
Unsecured lending to households	3978	2439.304	6188.257	0	42309.52
		per cent			
Total lending growth	3474	1.693999	8.556637	-23.6508	34.83484
Household lending growth	3275	0.963405	9.663742	-34.6899	43.11927
PNFC lending growth	3389	1.824463	10.10389	-26.2055	40.45848
Secured lending growth	2667	0.217652	5.57018	-22.9219	18.60189
Unsecured lending growth	2967	1.717776	6.267442	-16.0981	31.81272
		per cent			
Capital requirements	2176	9.670173	1.324076	8	13.58488
Capital buffer	2599	7.313729	8.241084	0.780774	39.41779
		percentage points			
ΔCapital requirements	1445	0.015852	0.269116	-2.65808	3.177661
ΔCapital buffer	1795	0.018363	1.280993	-15.9491	11.30077

Table 6.1 describes the main variables that we use in this paper. Total lending is the stock of lending to households and to private non-financial corporates (PNFC), i.e. total non-financial lending. Secured lending and unsecured lending are lending to households secured by residential property and unsecured lending to households respectively. Growth variables are the quarter over quarter percentage changes of stock variables. Among the growth variables, PNFC lending has the highest variance, while secured lending growth the lowest.

6.4. Econometric strategy and results

Our strategy is to investigate the transmission mechanism of capital requirements in two separate steps, reflecting the structure described in Figure 6.2. First, we investigate the effects of changes in capital requirements on bank capital ratios. As discussed previously, capital requirements have to have an effect on capital ratios for the transmission mechanism to work (i.e. capital requirements are binding). Once we have established that this relationship exists, we aim to investigate the effects of capital requirements on bank lending. We will also exploit the panel data nature of our dataset and investigate heterogeneity of the effects of capital requirements, in particular focusing on the differences between large and small banks.

Throughout the paper we are going to treat this panel dataset as a *time-series* panel dataset, as we would expect that our results will be largely determined by the time-series dimension within individual banks. Indeed for changes in total lending and changes in trigger requirement (our key variables), within variance explains around 95% of the total variance. This indicates that the cross-section dimension is not likely to contribute much to our estimates.

The relevance of the time-series dimension in the panel dataset may add two potential problems to the estimation process. First, the variables we have included in the specification may not be stationary, and this may cause our estimated relationship to be spurious. However, we consider changes of the main variables, so that even if they were originally integrated of order one, taking changes would make them stationary.

Second, including the lags of the dependent variable generates biased estimates creates the so-called 'lagged dependent variable' bias (Bond, 2002). In this case OLS estimates are inconsistent because the lagged dependent variable is correlated with the error term as both terms include a bank-specific error term. The Fixed Effects estimator eliminates this source of inconsistency by transforming the variables and eliminating the bank specific error term. But the transformed lagged dependent variable is now correlated with the error term so that the Fixed Effects (FE) estimator is also inconsistent.

Bond (2002) shows that this inconsistency decreases as the number of observations increases as long as the error terms are not autocorrelated. In our large T dynamic panel regressions we have lagged dependent variables and lagged exogenous variables and autocorrelation should not affect the consistency of our estimates.

The Generalised Method of Moments (Arellano and Bond, 1991) is often used to tackle these inconsistency problems in large N, small T panels. However, for large T, the Fixed Effects estimator will be close to the GMM estimator and provides a better alternative given the reported poor small properties of the GMM estimator (Verbeek, 2012). Therefore our preferred approach will be to estimate the regressions by using the FE estimator.

6.4.1. Are changes in capital requirements affecting bank capital?

For the transmission mechanism to work, changes in capital requirements have to affect financial institutions' capital ratios, i.e. capital requirements are binding. This means that, when the macroprudential regulator changes regulatory capital, banks adjust their capital ratio effectively, affecting the capacity of banks to lend. This is because a change in *binding* capital requirements affects the capital structure.

Changes in capital ratio are likely to be affected by previous changes in capital ratio, changes in capital requirements, bank characteristics and macroeconomic factors. For example, Ediz et al. (1998) regress capital ratios on a set of bank specific variables (including capital requirements) using a panel of UK banks. This specification however lacks macroeconomic variables, which are on the other hand included in other seminal papers on the relationship between capital variables and banks' behaviour, e.g. Bernanke and Lown (1991) and Hancock and Wilcox (1998). Francis and Osborne (2009) suggest that there is an established empirical relationship between macroeconomic activity and banks' capital ratios.

Capital requirements may not bind in some states of the world. For example, lowering capital requirement during a financial crisis may not affect the desired levels of capital as 'market requirements' may bind (Wall and Peterson, 1995 and Barrios and Blanco, 2003).[7] In this case financial markets may require a capital ratio that is higher than the regulatory requirement as market participants sell equities of banks that have a capital ratio lower than the perceived market requirement. On the other hand, increasing capital requirements in an upturn may bind as banks generally hold smaller buffers with strong macroeconomic conditions because expected losses in an upturn are limited. For example, before the current financial crisis capital ratios of UK banks were exceptionally low and increased after the beginning of the crisis (see Bank of England, 2012)

In order to incorporate bank specific and macroeconomic factors, we specify the capital equation as follows:

[7] The market capital requirement is the level of the capital ratio under which financial institutions would incur into liquidity or solvency problems. This is unobservable by the regulator and the financial markets.

$$\Delta C_{it} = \alpha + \beta(L)\Delta C_{it} + \gamma(L)\Delta T_{it} + \mu' I_{it} + \theta' A_t + u_{it} \tag{6.1}$$

where ΔC_{it} is quarterly changes in capital over risk weighted assets ratio for bank i in period t[8], ΔT_{it} is changes in trigger capital requirement, I_{it} is a vector of bank specific (micro) controls (capital requirements, provision ratio and bank size) and A_t is a vector of macro controls (Unemployment, Equity returns, GDP growth and Bank of England base rate). u_{it} is a normally distributed error term with mean zero and variance $\sigma^2, u_{it} \sim N(0, \sigma^2)$.[9] L is a lag operator where $\beta(L) = \sum_{s=1}^{4} \beta_s(L^s)$, $\gamma(L) = \sum_{s=0}^{4} \gamma_s(L^s)$.

For the transmission mechanism to be effective, a change in capital requirements (T) should have a positive and statistically significant coefficient. Changes in capital requirements can have short-run and long run effects. The former are identified by the coefficients of the individual time lags, while the latter are identified by the sum of the lagged coefficients divided by one minus the sum of lagged lending coefficients.[10] Using data on UK banks, Ediz et al. (1998) and Francis and Osborne (2009) find evidence that changes in capital requirements are binding. However, empirical evidence for other countries is mixed (VanHoose (1997)).

[8] For example, if in time t=1 the capital ratio is 10 percentage points and in time t=2 the capital ratio is 12 percentage points, the change is 2 percentage points. The same applies to trigger capital changes.

[9] It is also generally assumed that the error terms are independent both in time and cross-section dimensions, i.e. $E(u_{it}, u_{js}) = 0$ for $i \neq j, s \neq t$.

[10] Using this specification we are able to estimate the long run effects of changes in deposit ratio on bank lending growth. This effect is defined as the cumulative effect of a change in deposit ratio on lending growth as time goes to infinity. However this effect should not be confused with the effect on the long-run lending growth, which we constrain to be zero. This is because the model is estimated in growth rates and there is no long-run levels relation.

Bank specific factors like size and provisions are also likely to affect financial institutions decisions on capital. Large (and systemic) banks are often reported to hold a smaller buffer of capital and this is also true in our sample. Large banks can benefit from lower funding costs, because of an easier access to capital markets and the presence of an implicit government guarantee (Ueda and Weder di Mauro (2012), Noss and Sowerbutts (2012)). Large banks are also more likely to have received capital injections during the financial crisis and this is likely to have a positive effect on bank lending (Brei et al. (2013)). And larger and more diversified banks may be less risky and therefore face lower funding costs. This will translate into higher profits and therefore a higher level of capital. A high level of provisions may lead to a higher capital ratio, given that the bank may expect larger losses in the future.

Macroeconomic activity can affect banks' capital ratios. For example, better macroeconomic variables may lead to lower capital ratios as financial institutions are less concerned about future losses. On the other hand, better economic conditions mean also higher profits, higher retained profits and therefore higher capital ratios.

One potential problem with equation 6.1 is that we may have reverse causality, i.e. changes in capital affect changes in trigger capital. For example, if a bank experiences large losses (and the capital ratio drops), the regulator may increase trigger capital as the riskiness of the bank increases. However, as described earlier on, capital requirements are set every 18 to 36 months and do not necessarily change promptly in response to changes in bank's capital ratio. Therefore, this institutional setting of capital requirements reduces the extent to which they are endogenous in our regressions.[11]

[11] Moreover, Granger causality tests suggest that changes in capital requirements Granger cause changes in capital ratios and *not* vice versa.

Table 6.2 presents the estimates for regression 6.1.[12] In specification (a) we have used Pooled Ordinary Least Squares regression with macro controls to estimate the effects of changes in capital requirements on the risk weighted capital ratio. Changes in regulatory capital lead to an increase in capital ratio.[13] In the short run, a 1pp change in trigger capital leads to a 0.5pp change in capital ratio. The long run coefficient remains statistically significant and is around 1.3pp.[14] It is difficult to interpret the short term effects of macro controls as signs vary with lags and both long run coefficients for these macroeconomic variables are not statistically significant. Stock market returns do not seem to affect bank capital ratios which seems in contrast with binding market capital requirements, i.e. changes in financial market conditions do not drive changes in capital resources. Overall, macroeconomic factors do not seem to affect bank capital ratios.

Given that estimates (a) may be biased, in specification (b) we have used Fixed Effects (FE). The fixed effects are significant, suggesting that POLS estimates are not consistent. The estimates maintain the same sign even though the short run effect of trigger capital declines somewhat to 0.3pp while in the long run the coefficient drops to 0.9pp.

These results indicate that changes in capital requirements have a positive and statistically significant effect on capital ratios, in line with other empirical research on UK

[12] Also the sample used in the regressions is not the full sample of banks because cases with missing observations on any variable are excluded. If the missing cases are systematically related to observed characteristics then there might be sample selection bias, e.g. survivorship bias if only firms that survive are included in the sample and they are systematically different from the excluded failed firms. While sample selection bias is fairly easy to deal with in cross-section, it is more difficult to deal with in dynamic panels of the type used here, so allowing for this is a topic for future research (e.g. using the procedure proposed recently in Semykina and Wooldridge (2013)).

[13] Results are robust to the exclusion of macroeconomic controls.

[14] Estimates and tests not presented here are in the Annex.

Table 6.2. Capital ratio and capital requirements regression

VARIABLES	(a) ΔCap.	(b) ΔCap.	(c) ΔCap.	(d) ΔCap. (l)	(e) ΔCap. (s)
ΔCap. ratio (-1)	0.793***	0.715***	0.715***	0.764***	0.714***
ΔCap. ratio (-2)	-0.663***	-0.679***	-0.680***	-0.873***	-0.670***
ΔCap. ratio (-3)	0.430***	0.370***	0.370***	0.565***	0.361***
ΔCap. ratio (-4)	-0.198***	-0.224***	-0.223***	-0.264***	-0.220***
ΔCap. req.	0.507***	0.346***	0.392***	-0.290	0.411***
ΔCap. req.*lar			-0.644		
ΔCap. req.(-1)	-0.127	-0.0446	-0.0792	0.0752	-0.0959
ΔCap. req.(-2)	0.335**	0.286*	0.310*	0.213	0.332
ΔCap. req.(-3)	-0.133	-0.116	-0.137	0.0774	-0.152
ΔCap. req.(-4)	0.246**	0.238*	0.276**	-0.0860	0.294**
ΔCap. req.(-1)*lar			0.240		
ΔCap. req.(-2)*lar			-0.0189		
ΔCap. req.(-3)*lar			0.0435		
ΔCap. req.(-4)*lar			-0.378		
Provisionratio (-4)	0.00703	0.0124	0.00913	-0.00104	-0.000283
Crisis	-0.127	-0.130	-0.136	-0.0544	-0.224
Bank size	0.00875	0.0783	0.0813	0.0651	0.0903
Unemployment	0.0202	-0.00790	-0.00761	0.00765	-0.0136
Equity returns	-0.00441	-0.00425	-0.00435	0.000997	-0.00635
GDP growth	0.0709	0.0875	0.0814	0.0126	0.0789
GDP growth (-1)	0.0665	0.0437	0.0458	0.0437	0.0281
GDP growth (-2)	-0.222**	-0.214**	-0.215**	-0.111	-0.254**
GDP growth (-3)	0.00423	-0.0164	-0.0284	0.00935	-0.000231
GDP growth (-4)	0.117*	0.0852	0.0891	0.00649	0.133
BoE rate	-0.158*	-0.124	-0.128	0.0537	-0.173
BoE rate (-1)	0.284*	0.237	0.240	-0.192	0.361
BoE rate (-2)	-0.366**	-0.301*	-0.291*	-0.0117	-0.400*
BoE rate (-3)	0.371**	0.304**	0.292*	0.227*	0.352*
BoE rate (-4)	-0.147*	-0.125	-0.120	-0.103	-0.141
Constant	-0.132	-0.670	-0.694	-0.663	-0.733
Observations	1,107	1,107	1,107	261	840
R-squared	0.380	0.356	0.357	0.422	0.358
Number of banks	42	42	42	10	31

Standard errors omitted
** p<0.01, ** p<0.05, * p<0.1

banks (e.g. Ediz et al. (1998), Alfon et al. (2004) and Francis and Osborne (2009)). Depending on the estimates, the effect of a 1pp change in trigger capital requirement leads to a 0.9-1.3pp change in the capital ratio. For the FE regression, the long run coefficient is not statistically different from 1, suggesting that financial institutions try maintain a *constant* capital buffer above the capital requirement.

In (a) and (b) we assume that the response to a change in capital requirements is homogeneous across banks. However, large and small banks may react differently to a change in capital requirements - for example large banks may react less given their better access to capital markets. In this case large banks may be able to operate with smaller capital buffers and raise equity when approaching the regulatory threshold. Moreover, systemic banks may benefit from lower funding costs, because of an easier access to capital markets and the presence of an implicit government guarantee (Ueda and Weder di Mauro (2012), Noss and Sowerbutts (2012)). This may allow large banks to accumulate capital more quickly following a capital shock.

To our knowledge, there is no theoretical framework providing priors on the magnitude of the coefficients for large and small banks even though our simple theoretical framework suggests that small banks may react more sharply to a change in capital requirements given their higher cost of accessing capital markets (see Chapter 4).

In (c) we let only the capital requirement coefficient vary for large and small banks, with all the other coefficients constrained to be equal. A large bank is any bank that has been on the top five according to assets at any period during the sample.[15] The

[15]Throughout the sample eight banks are classified as large.

coefficients of the interaction variables are not statistically significant, which may suggest that large and small banks do not react differently to a change in capital requirements.

In (d) and (e) we run two separate regressions for large and small banks respectively, allowing all the coefficients to differ. In this case large and small capital requirements coefficient differ largely. For small banks, the effect of changes in trigger capital on capital is positive and statistically significant and the long run coefficient is not statistically different from 1 while the coefficients (including the long run coefficient) for large institutions are not statistically significant.[16]

These results suggest that large and small institutions react differently to a change in capital requirements. In other words, small institutions maintain a constant capital buffer above the trigger capital, while large banks do not change their capital ratios following changes in trigger capital. The lack of response to a change in capital requirements can potentially affect the transmission mechanism of capital requirements for large banks. If large banks' capital requirements are not binding there is no reason why a change in capital requirements will affect large banks' lending (see Figure 6.2). We investigate the effect of capital requirements on bank lending in the following subsection.

6.4.2. How does a change in capital requirements affect bank lending growth?

Bank lending growth is likely to be affected by bank specific (supply) and macroeconomic (demand) factors (Bernanke and Lown, 1991). Starting from the micro factors, capital

[16]The statistical insignificance of the capital requirement for large institutions could be due to the fact that changes in trigger requirements vary less for large institutions than for small institutions. The two coefficients may then not be statistically different because of the large standard errors on large institutions' coefficients. However, the standard errors of the trigger coefficient are similar in magnitude and the long run coefficients are statistically different.

variables (i.e. capital requirements) and capital buffers are likely to affect lending growth (Francis and Osborne (2010)).[17] An increase in capital requirements should lead to a decline in lending growth as it acts as a shock to capital, e.g. Bernanke and Lown (1991) and Peek and Rosengren (1997) find that a shock to capital reduces lending supply. We now look at the various controls in more detail and describe our priors on the sign of the various estimates.

As discussed earlier, a change in capital requirements acts as a shock to capital. In our case, a change in capital requirements reduces the capital buffer, and banks will have to make up the difference either by issuing fresh equity or by cutting lending. Alternatively, banks could reduce the riskiness of their assets by switching from high risk weighted assets to low risk weighted assets.

A higher *level* in capital buffer should be related to higher lending growth as banks are better placed to withstand adverse economic shocks (e.g. Bernanke and Lown (1991)). Also a lower capital buffer should affect lending growth negatively as banks try to stay above the regulatory capital threshold by cutting lending. But an *increase* in capital buffer may be costly, e.g. because of an adverse selection problem (Myers and Majluf (1984)). As funding costs rises, banks may cut lending in response.[18] Also, if the capital ratio is replenished by cutting lending, the buffer-lending relationship may be negative, i.e. we may have a reverse causality problem.[19]

[17] Capital buffer is defined as the difference between total capital and trigger requirement.

[18] In this analysis we restrict the effect of capital buffers on long run lending growth to be zero and therefore we will include only changes of capital buffers in the lending regression. In other words, we assume that the Modigliani-Miller theorem holds in the long run and that the effect of changes in the capital structure does not have an effect on long run lending growth.

[19] We test for reverse causality problem in subsection 6.4.3.

Total provisions affect lending growth because higher provisions give an indication of banks' expected losses and riskiness of banks' asset side. As the bank expects larger losses, it may decide to reduce lending to preserve its capital buffer in the future. Banks' size could also affect banks' capacity to lend. Large (and systemic) banks can benefit from lower funding costs, because of an easier access to capital markets and the presence of an implicit government guarantee (Ueda and Weder di Mauro (2012), Noss and Sowerbutts (2012)). And larger and more diversified banks may be less risky and therefore face lower funding costs. This will translate into higher profits and therefore a higher level of capital and lending. Being a foreign-owned bank or a non-bank financial institution may affect lending growth. In particular, a foreign subsidiary may react differently to a shock to capital as its lending decisions may be also a function of economic and regulatory conditions of the home market (Peek and Rosengren (1997), de Haas and van Lelyveld (2011), Fidrmuc and Hainz (2013)).

We have also included a set of standard macro variables such as GDP growth, unemployment rate, Bank of England base rate and changes in stock market prices which aim to control for demand for bank lending.[20] To capture structural changes in lending patterns, we have also included a 'crisis' dummy variable that takes value one from the first quarter of 2008 until the end of the sample.

More formally, the relationship between lending and balance sheet and macroeconomic variables can be expressed by an Auto Regressive Distributed Lag (ARDL) model :

[20] These variables do not control for sectoral demand shocks. For example, if there is a specific shock to real estate companies, banks that lend to real estate will be strongly affected and their lending may decline sharply. In this case macroeconomic variables may not pick up this effect.

$$\Delta l_{it} = \alpha + \beta(L)\Delta l_{it} + \gamma(L)\Delta T_{it} + \delta(L)\Delta B_{it} + \mu' I_{it} + \theta' A_t + u_{it} \tag{6.2}$$

where Δl_{it} is quarterly lending growth for bank i in period t, ΔT_{it} is changes in trigger capital requirement, ΔB_{it} is changes in capital buffer, I_{it} is a vector of micro controls and A_t is a vector of macro controls. u_{it} is a normally distributed error term with mean zero and variance $\sigma^2, u_{it} \sim N(0, \sigma^2)$.[21] L is a lag operator where $\beta(L) = \sum_{s=1}^{4} \beta_s(L^s)$, $\gamma(L) = \sum_{s=0}^{4} \gamma_s(L^s)$ and $\delta(L) = \sum_{s=0}^{4} \delta_s(L^s)$.

We start by estimating equation 6.2 using OLS and we then test for fixed effects. We then also test the restriction that the individual bank error term is uncorrelated with the regressors (random effects).

The key parameters of interest are the effect of a change in capital requirements γ and capital buffers δ on bank lending growth. Table 6.3 presents the estimates of equation 6.2 for various specifications. In (a) we estimate 6.2 using Pooled Ordinary Least Squares (POLS) with bank controls only.

As expected, a change in capital requirements has a negative and statistically significant effect (1% confidence level) on lending growth. In the short term, a 1pp increase in capital requirements leads to a 4.7pp reduction in lending growth. Its long-term effect remains negative, around 6pp, and statistically significant. An increase in capital buffer has a mildly negative effect on lending growth (it is significant at a 1% level) - a 1ppt

[21] We assume that the error terms are independent both in time and cross-section dimensions, i.e. $E(u_{it}, u_{js}) = 0$ for $i \neq j, s \neq t$.

increase in the buffer is related to a 1.1pp decline in lending. Differently from capital requirements, this effect is no longer statistically significant in the long term.

The effect of a change in capital buffers is likely to work in the opposite direction of a change in trigger requirements. As the macroprudential regulator decides to increase capital requirements, the buffer will decline (buffer equals total capital ratio minus capital requirements), offsetting some of the lending growth decline generated by the increase in capital requirements. Taking into account the combined effects, a 1pp increase in trigger requirement will lower lending growth by 3.6pp in the short term.[22] For example, if banks are lending at 10% growth rate, an increase in capital requirements will bring lending growth to 6.4% in the short run.

Bank size is associated to lower lending growth (significant at a 10% level), while the crisis dummy is not statistically significant. Dummy variables for non-bank financial institution and foreign subsidiary are also not statistically significant. This could be due to the small number of observations for these types of financial institutions.

Specification (b) presents OLS estimates with macroeconomic variables. We have included variables to capture general economic activity (e.g. changes in GDP and unemployment rate) and variables that are likely to affect bank lending growth (e.g. Bank of England base rate and changes in UK stock prices)[23]. Parameters are little changed and capital requirements and capital buffer still have a negative sign and are highly significant. Changes in equity returns affect lending growth and the coefficient has the positive expected sign, i.e. with stronger equity markets, lending growth is higher. This may

[22]This is derived by subtracting -4.7 and -1.1 which are the trigger requirement and capital buffer coefficient estimates presented in Table 2.

[23]Here we have included FTSE100 returns.

be because when equity prices increase the cost of bank equity declines, which in turn leads to lower funding costs and higher bank lending. Surprisingly real GDP changes and Bank of England base rate levels do not affect lending growth which is in line with recent empirical work, e.g. Ayiar et al. (2012).

We have then estimated the same regression with bank-specific and macroeconomic controls using the Fixed Effects estimator, FE (c).[24] The Fixed Effects are significant, therefore POLS estimates are not consistent. However the bias is probably not large as the trigger requirement coefficient is similar to POLS estimates and it is still significant at a 1% level. The capital buffer coefficient declines somewhat (around 0.2pp) and loses some significance.

In (d) we have estimated the model using two-way FE and for this reason we have excluded macro variables to avoid double counting. The R^2 increases by around 6pp and trigger requirement and capital buffer remain statistically significant. The coefficients are broadly in line with one-way FE estimates even though several criteria suggest that the FE specification should be preferred.[25]

6.4.3. Capital buffers and endogeneity issues

As discussed previously, the negative coefficient on changes in capital buffer may be related to the fact that raising capital is costly which leads to higher funding costs and therefore

[24]We do not present Random Effects (RE) estimates because a Breusch-Pagan Lagrange Multiplier test suggests that we cannot reject that the variance of the individual effects is zero. Therefore RE does not capture well the nature of the data generating process.

[25]In order to select the best specification between (c) and (d) we have performed a likelihood ratio test. The test does not reject the null that the time effects are zero. Moreover, both the Akaike Information Criterion and the Bayesian Information Criterion confirms that the one-way FE model better fits the data than the two-way FE model.

Table 6.3. Total lending regressions

VARIABLES	(a) Lend. g.	(b) Lend. g.	(c) Lend. g.	(d) Lend. g.
Lending growth (-1)	0.00484	0.00637	-0.0362	-0.0318
Lending growth (-2)	0.160***	0.154***	0.0953***	0.111***
Lending growth (-3)	0.0754**	0.0755**	-0.00466	0.00850
Lending growth (-4)	0.0530	0.0537	0.0171	0.0168
ΔCap. req.	-4.665***	-4.992***	-4.728***	-4.675***
ΔCap. req. (-1)	1.263	2.033	1.429	0.813
ΔCap. req. (-2)	1.451	1.112	1.019	1.154
ΔCap. req. (-3)	-2.853**	-2.850*	-2.816*	-2.582
ΔCap. req. (-4)	0.711	0.744	0.365	0.908
ΔCap. buf.	-1.131***	-1.121***	-0.870**	-0.809**
ΔCap. buf. (-1)	0.309	0.295	0.00577	0.0157
ΔCap. buf. (-2)	-0.186	-0.0951	0.0414	0.0802
ΔCap. buf. (-3)	-0.0467	-0.0623	-0.312	-0.314
ΔCap. buf. (-4)	0.382**	0.370**	0.677***	0.707***
Provision ratio (-4)	-0.982	-0.872	-2.794***	-3.620***
Crisis	0.864	1.687	0.699	1.571
Bank size	-0.236*	-0.273*	0.560	-0.0187
Foreign sub.	0.498	0.483		
Non-bank	0.764	0.754		
Unemployment		-0.121	-0.0729	
Equity returns		0.0616**	0.0744**	
GDP growth		0.856	0.922	
GDP growth (-1)		-0.936	-0.877	
GDP growth (-2)		0.984	0.967	
GDP growth (-3)		-0.677	-1.026	
GDP growth (-4)		0.551	0.586	
BoE rate		-1.104	-1.094	
BoE rate (-1)		1.233	1.184	
BoE rate (-2)		0.911	0.996	
BoE rate (-3)		-1.560	-1.809	
BoE rate (-4)		0.468	0.628	
Constant	4.080***	4.863**	-2.625	4.202
Observations	919	919	927	919
R-squared	0.088	0.103	0.088	0.154
Number of banks			40	39

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

lower lending. An alternative interpretation could be that the capital buffer variable may have a negative correlation with lending by construction, i.e. increases in capital buffer are achieved by cutting lending rather than issuing capital. This could be potentially an endogeneity issue, where capital buffers and lending decisions are taken simultaneously. We have therefore estimated a panel VAR for changes in lending growth and changes in capital buffer, with lending and capital buffer the only endogenous variables.[26] The system of equations looks as follows:

$$\Delta Y_{it} = \alpha + \beta(L)\Delta Y_{it} + \gamma(L)\Delta T_{it} + \delta(L)\Delta B_{it} + \mu I_{it} + \theta A_t + u_{it} \tag{6.3}$$

where $\Delta Y_{it} = [\Delta l_{it}, \Delta C_{it}]', \beta = [\beta_{1,}\beta_2]', \gamma = [\gamma_1, \gamma_2]', \delta = [\delta_{1,}\delta_2]', \mu = [\mu'_{1,}\mu'_2], \theta = [\theta'_{1,}\theta'_2]$. Variables with subscript 1 refer to the lending regression, while variables with subscript 2 refer to the capital buffer regression. Variables and lag operators are defined as in 6.2.

If increases in capital buffers are driven (in Granger causality terms) by a reduction in lending we would expect the lagged lending coefficients in the capital buffer equation, β_{21}(i.e. the coefficient of the lending variable in the second equation), to be negative and jointly statistically significant. However, a joint test of significance of the lagged lending variables rejects this hypothesis so that we can tentatively infer that the negative coefficient is linked to the cost of capital story rather than endogeneity issues.[27]

[26]In other word this is a panel VAR with exogenous variables. In each regression we have included four lags of total lending growth and four lags of changes in capital buffer and we have excluded the contemporaneous endogenous variables.

[27]However, this evidence is far from being conclusive and further analysis should be devoted to this issue. Indeed a Breusch-Pagan test rejects the independence of the two equations as the correlation coefficient

6.4.4. Are large and small banks reacting differently to an increase in capital requirements?

Specification 6.2 assumes that the capital coefficients are homogeneous across types of institutions, so that for a bank of type $i \neq j$, $\gamma_i = \gamma_j$ and $\delta_i = \delta_j$. However, it may be the case that capital coefficients change with bank characteristics, i.e. for bank of type $i \neq j$, $\gamma_i \neq \gamma_j$ and $\delta_i \neq \delta_j$. From a policy perspective this distinction is particularly relevant. If, for example, a change in capital requirements affect only small banks, the total effect on overall lending could be smaller than if the change affected all banks in the same way.[28]

One way to examine this issue would be to include interaction variables for capital variables in equation 6.2, where trigger requirement and capital buffer are interacted with dummies that take value one for large banks. If capital coefficients vary for these types of banks we would expect the interactions to be statistically significant. For a given increase in trigger capital, large banks may find it easier to access capital markets than smaller banks allowing large banks to operate with smaller capital buffers. This may mean that smaller banks may react more sharply to a regulatory change.

This hypothesis is consistent with the literature on transmission mechanism of monetary policy, where empirical evidence suggests that an increase in interest rates affects small banks more than large banks (Kashyap and Stein, 1994) and also with our simple theoretical model on the effects of capital requirements on bank lending.

between the errors is around -0.10. This may indicate that there is a certain degree of correlation between lending and capital buffers.

[28]In our sample, 60% of total lending was from large banks in Q4 2010.

Table 6.4, specification (a), presents FE estimates with interaction variables for the capital coefficients for small and large banks, with all the other coefficients constrained to be the same.[29] Interaction variables are not statistically significant for any capital variable, which may indicate that small and large capital coefficients are similar.

However, this specification assumes that only capital parameters can vary. In (b) and (c) we run separate FE regressions for large and small banks respectively. While the large banks' regression (b) indicates that the capital coefficients are small and not statistically significant (but they maintain the expected negative sign), the small banks coefficients (c) are large and statistically significant. For small banks, a 1pp increase in capital requirements leads to a 5pp decline in lending in the short run[30], which compares with a 3.7pp change in the pooled regression.

These results suggest that small and large banks react differently to a change in trigger capital requirements and are consistent with our earlier findings that capital requirements are not binding for large banks.[31] Therefore, the capital coefficients that we observe in the total lending regression are mainly driven by small banks. As discussed previously, this heterogeneity may be due to large banks better access to capital markets so that, following a regulatory shock, they are able to operate with smaller capital buffers instead of reducing bank lending.[32]

[29]The relevant variables are 'ΔCap. req. * lar' with its lags and 'ΔCap. buf. * lar' with its lags.

[30]We have considered the joint effect of trigger requirement and capital buffer.

[31]The variability of changes in trigger requirements for large banks is lower than that for small banks. In this case standard errors of the large coefficient may be so large that the distribution of the large coefficient may include the distribution of the small coefficient. If true, large and small coefficients may not be statistically different after all. However, this hypothesis is rejected, as standard errors of small and large banks coefficients are similar and their distributions barely overlap.

[32]We also performed a Chow test on the POLS regression to check whether all the coefficients were statistically different. The test suggests that the large and small specifications are not statistically different. However, the Chow test assumes that the error terms of both groups (in our case large and

Table 6.4. Lending regression for large and small banks

VARIABLES	(a) Lend.g.	(b) Lend.g. (large)	(c) Lend.g. (small)
Lending growth (-1)	-0.0350	0.0872	-0.0427
Lending growth (-2)	0.0958***	-0.00323	0.101**
Lending growth (-3)	-0.00848	0.0338	-0.0155
Lending growth (-4)	0.0172	0.0567	0.0161
ΔCap. req.	-5.200***	-0.455	-5.928***
ΔCap. req. * lar	4.190		
ΔCap. req. (-1)	1.060	0.814	1.789
ΔCap. req. (-2)	1.664	-0.580	1.339
ΔCap. req. (-3)	-3.655**	-0.336	-3.713*
ΔCap. req. (-4)	0.814	0.135	0.959
ΔCap. req. * lar (-1)	0.814		
ΔCap. req. * lar (-2)	-2.332		
ΔCap. req. * lar (-3)	2.953		
ΔCap. req. * lar (-4)	-1.686		
ΔCap. buf.	-0.936**	-0.239	-0.960**
ΔCap. buf. * lar	0.479		
ΔCap. buf. (-1)	-0.0217	0.210	-0.0598
ΔCap. buf. (-2)	0.0417	-0.346	0.150
ΔCap. buf. (-3)	-0.279	0.0845	-0.295
ΔCap. buf. (-4)	0.699***	-0.0730	0.712***
ΔCap. buf. * lar (-1)	0.291		
ΔCap. buf. * lar (-2)	-0.413		
ΔCap. buf. * lar (-3)	0.290		
ΔCap. buf. * lar (-4)	-0.955		
Bank controls	yes	yes	yes
Macro controls	yes	yes	yes
Constant	-2.666	8.584	-3.510
Observations	919	330	589
R-squared	0.092	0.101	0.110
Number of banks	39	10	29

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

In dynamic models, biases may arise if homogeneity of the coefficients is inappropriately imposed (Pesaran and Smith, 1995). This is because coefficients' heterogeneity may introduce autocorrelation of the error terms which in conjunction with the lagged dependent variable will make the estimates inconsistent. To relax the homogeneity assumption in the FE estimator we have estimated equation 6.2 using the Mean Group estimator for large and small banks (Pesaran and Smith, 1995), where the number of the observations allowed.[33]

In this case our estimate of the effect of the capital variables on lending will be the following:

$$\gamma_{MGE} = \frac{1}{N}\sum \hat{\gamma}_i \tag{6.4}$$

$$V(\gamma_{MGE}) = 1/N(N-1)\sum(\hat{\gamma}_i - \gamma_{MGE})(\hat{\gamma}_i - \gamma_{MGE})' \tag{6.5}$$

where γ_{MGE} is the Mean Group estimator and $\hat{\gamma}_i$ is the estimated coefficients for bank i. We have estimated δ_{MGE} and V(γ_{MGE}) using the same approach.

Unfortunately, the results are inconclusive as all the capital coefficients are not statistically significant due to large estimated variance of the mean group estimator. This is probably due to the limited number of observations for some banks and the highly unbalanced nature of our dataset.

small banks) are normally distributed with equal variance σ^2. The hypothesis that the estimated variance of the residuals is the same is rejected, casting some doubts on Chow test results.

[33]We have used 5 large banks and 4 small banks to estimate coefficients for large and small banks. Main results are included in the Annex.

6.4.5. Effect of a change in capital requirements on sectoral lending

In the previous section we regressed *total* lending growth on a set of macroeconomic and bank balance sheet variables and we found that capital requirements affect bank lending growth. But total lending growth is constructed by summing up lending to households (both secured and unsecured) and lending to PNFCs. In this case, the richness of the dataset allows us to test whether the effect of changes in capital requirements vary for different lending sectors. This can have important policy implications as the macroprudential regulator may want to act on booms (or busts) of particular lending sectors (Bank of England, 2012a).

Table 6.5 presents various estimates for household secured, unsecured lending and lending to PNFCs. For simplicity we present only FE estimates. The results differ from what we have seen in the total lending regressions. For the secured lending regression (a) the capital coefficients lose significance, even though they maintain the expected signs.

In the unsecured lending regression the capital requirement coefficient becomes highly significant, while the capital buffer coefficient loses significance. For a 1pp increase in capital requirements banks reduce unsecured lending by around 5pp in the short term. The long run coefficient is also statistically significant. Unsecured lending is usually riskier than secured lending, so this could indicate that given an increase in trigger requirement financial institutions decide to reduce unsecured lending and curb risk-weighted assets.

The coefficient of trigger requirement on lending to PNFC has an unexpected sign on the second lag, i.e. for an increase in trigger requirement we observe an increase in lending to this type of lending but the long run coefficient is not statistically significant. However, these estimates maybe driven by differences in the sample used for each lending regression. For example, it may be possible that banks operating only in the unsecured market may be structurally more sensitive to a change in capital requirements. In this case our estimate will be biased upwards.

Banks may react to a change in regulatory policy with a reduction in lending growth. However, banks may decide to switch from one type of lending to another without necessarily reducing lending growth. In this case RWA will decline and the bank will be able to comply with regulatory changes. Unfortunately the theoretical literature does not seem to agree on the effects of capital regulation on asset risk; depending on the assumptions made in the model, an increase in capital requirements could increase or decrease banks' risk taking (VanHoose, 2007).

In practice, given that riskier lending (e.g. unsecured and PNFC) attracts higher capital surcharges, we would expect banks to switch from riskier to safer lending to reduce their risk-weighted assets in order to boost their capital ratio. To assess whether banks change the composition of their lending book we have estimated a multivariate panel regression with exogenous variables (VARX) as follows:

$$\Delta l_{it}^{j} = \alpha_i^j + \sum_{j=1}^{3} \beta^j(L)\Delta l_{it}^{j} + \gamma^j(L)\Delta T_{it} + \delta^j(L)\Delta B_{it} + \mu^{j\prime} I_{it} + \theta^{j\prime} A_t + u_{it} \tag{6.6}$$

For $i = 1, 2$ and 3, where $j = 1$ for secured lending to households, $j = 2$ for unsecured lending to households and $j = 3$ for lending to PNFCs. Lag operators and explanatory variables are defined as in equation 6.2.

Table 6.6 presents the estimates for the system of equations 6.6. In the short term, financial institutions change the composition of their lending following an increase in

Table 6.5. Regressions for secured, unsecured and lending to PNFCs

VARIABLES	(a) Sec. lend. g.	(b) Unsec. lend. g.	(c) Pnfc lend. g.
ΔCap. req.	-0.0214	-4.660***	-1.338
ΔCap. req. (-1)	1.388	-2.110	6.015***
ΔCap. req. (-2)	-0.210	0.578	-0.500
ΔCap. req. (-3)	-0.562	-0.104	-2.771
ΔCap. req. (-4)	-0.421	-0.158	3.552*
ΔCap. buf.	-0.148	-0.643	0.0662
ΔCap. buf. (-1)	0.533*	0.841	-0.200
ΔCap. buf. (-2)	0.130	-0.741	0.421
ΔCap. buf. (-3)	0.167	0.536	-0.241
ΔCap. buf. (-4)	0.332	-0.160	-0.375
Provision ratio (-4)	-0.602	-3.562***	-3.152**
Crisis	1.739*	1.187	1.741
Bank size	-1.467**	-2.100*	2.994**
Unemployment	-0.428**	0.211	-0.119
Equity returns	0.00812	-0.0436	0.0984**
GDP growth	-0.109	0.147	1.369
GDP growth (-1)	-0.00440	1.330	-1.269
GDP growth (-2)	0.571	-0.160	0.916
GDP growth (-3)	-0.342	-1.692*	-0.217
GDP growth (-4)	-0.431	0.858	0.991
BoE rate	0.101	-0.275	-1.558*
BoE rate (-1)	-0.266	-0.313	2.199
BoE rate (-2)	0.274	1.098	1.960
BoE rate (-3)	-0.298	-1.425	-2.463
BoE rate (-4)	0.229	0.703	0.620
Constant	18.92**	24.02*	-32.80**
Lagged lending growth	yes	yes	yes
Observations	750	920	837
R-squared	0.099	0.057	0.101
Number of banks	33	39	38

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

capital requirements. In particular, it appears that banks substitute away from PNFC lending. The capital requirement coefficient is lower than in the general specification and this can be due to two reasons. First, we are looking at a different specification, as we include lags of all the other types of lending as explanatory variables. Second, the number of observations is almost halved. Several institutions are dropped out of the sample as they do not operate in all the three types of lending sectors.

We have run two separate multivariate regressions for large and small banks using equation 6.6 to test whether changes in asset composition affect small and large banks in the same way. The estimates are presented in Table 6.7. The coefficients suggest that the adjustment in the asset composition is mainly driven by small banks. This is consistent with our earlier results, i.e. large banks are insensitive to changes in capital requirements.[34]

6.5. Conclusions

We find that changes in individual capital requirements affect lending growth. This is because capital requirements are binding and financial institutions try to maintain a constant buffer of capital above the capital requirement. A 1pp change in the capital requirements leads to a 4.7pp change in bank lending growth in the short-term. Changes in capital buffers have a negative (albeit smaller) impact on lending. A 1pp increase in the buffer leads to a decline of around 0.9pp decline in lending. When considering the combined effect of trigger requirement and capital buffer, a 1pp change in capital requirements leads to a 3.8pp change in bank lending growth in the short term. This

[34]The number of observations for these regressions decline dramatically compared to total lending estimates, and therefore these estimates should be interpreted with some care.

Table 6.6. VARX regression for secured, unsecured and lending to PNFCs

VARIABLES	(a) Lend. g.	(b) Sec. lend. g.	(c) Unsec. lend. g.	(d) Pnfc lend. g.
ΔCap. req.	-2.738**	-0.261	-0.106	-2.739**
ΔCap. req. (-1)	2.968*	1.492	-1.995	2.964
ΔCap. req. (-2)	0.116	-2.122	2.674*	0.393
ΔCap. req. (-3)	-1.131	-0.884	1.203	-1.453
ΔCap. req. (-4)	0.673	-0.102	0.653	1.606
ΔCap. buf.	-0.647*	0.409	-0.557	-1.689***
ΔCap. buf. (-1)	-0.175	0.393	-0.311	0.392
ΔCap. buf. (-2)	-0.491	0.393	-0.462	-0.680
ΔCap. buf. (-3)	0.970**	-0.385	-0.0735	0.691
ΔCap. buf. (-4)	-0.169	0.157	-0.144	-0.743*
Provision ratio (-4)	-1.222*	-1.025*	-0.584	-1.998**
Crisis	2.466**	0.580	-0.474	0.909
Bank size	-0.353**	0.0570	0.0808	-0.407**
Unemployment	-0.348**	-0.204	-0.315**	-0.364*
Equity returns	0.0595**	0.0156	-0.00346	0.0726**
GDP growth	0.478	0.0360	-0.0409	0.402
GDP growth (-1)	-0.00678	0.0832	0.335	-0.411
GDP growth (-2)	0.571	0.135	0.359	1.281*
GDP growth (-3)	0.521	-0.300	0.392	-0.326
GDP growth (-4)	-0.220	0.153	0.00213	-0.270
BoE rate	-0.337	0.0293	0.489	-0.415
BoE rate (-1)	0.250	0.196	-0.692	-0.0656
BoE rate (-2)	0.902	-0.219	0.223	1.349
BoE rate (-3)	-1.326	0.368	-0.523	-0.606
BoE rate (-4)	0.740	-0.228	0.620	-0.108
Constant	5.427**	0.897	1.625	7.455***
Lags	yes	yes	yes	yes
Observations	579	579	579	579
R-squared	0.180	0.501	0.230	0.337

** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6.7. VARX regressions for large and small banks

	Large banks				Small banks			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
VARIABLES	totlending	secured	unsecured	pnfc	totlending	secured	unsecured	pnfc
Cap. req.	-0.353	-0.0366	1.081	-0.223	-3.115*	-0.129	0.447	-3.858**
Cap. req.(-1)	0.680	0.290	-0.337	0.801	3.159	1.748	-4.807*	4.996
Cap. req.(-2)	-0.205	0.684	1.067	-2.541	0.496	-2.684	4.217	-0.645
Cap. req.(-3)	-1.568	0.0123	1.310	-5.072**	-1.404	-1.921	0.907	0.260
Cap. req.(-4)	0.393	0.501	-0.134	4.805**	0.984	-0.810	1.032	-0.0628
Cap.buf.	-0.301	-0.0991	0.0697	-0.531	-0.254	0.939**	-0.771	-1.963***
Cap.buf.(-1)	0.269	-0.177	-0.243	0.806	-0.721	0.646	-0.506	0.0961
Cap.buf.(-2)	-0.278	0.139	0.0980	-0.360	-0.178	0.659	-0.738	-0.617
Cap.buf.(-3)	-0.0988	-0.122	0.0181	-0.179	1.503**	-0.542	-0.0991	1.259*
Cap.buf.(-4)	-0.0684	0.198	-0.227	-0.407	-0.0443	0.231	-0.230	-0.965
Provision ratio(-4)	-1.548***	0.329	-1.609**	-1.911	-1.740	-1.296	-0.702	-2.378*
Crisis	2.060***	0.814	-1.164	2.018	3.717	0.647	-0.698	0.577
Bank size	-0.747***	-0.690***	-0.219	-0.534	-0.736*	0.194	0.228	-0.651
Unemployment	-0.449***	-0.538***	-0.369***	-0.429*	-0.260	-0.140	-0.276	-0.194
Equity returns	0.00735	-0.00986	-0.00845	0.00228	0.150***	0.0324	0.00796	0.167***
GDP growth	-0.233	-0.132	-0.291	-0.203	1.073	0.527	-0.611	1.009
GDP growth (-1)	-0.0688	-0.254	0.108	-0.284	-0.0546	0.476	0.316	-0.761
GDP growth (-2)	0.561	0.302	0.138	0.103	1.405	0.0236	1.126	2.690**
GDP growth (-3)	0.00286	-0.192	0.269	-0.0374	1.067	-0.490	0.734	-0.351
GDP growth (-4)	-0.320	0.0888	-0.303	-0.238	-0.151	-0.741	1.065	-0.902
BoE rate	0.316	0.00629	-0.185	0.864	-1.228	0.0749	1.214	-1.484
BoE rate (-1)	0.187	0.374	0.434	-0.321	0.316	-0.396	-1.999	0.405
BoE rate (-2)	-0.0404	-0.105	-0.521	0.475	1.830	-0.210	1.138	1.444
BoE rate (-3)	-0.411	-0.796	-0.338	0.538	-2.124	2.358	-1.104	-1.121
BoE rate (-4)	0.0347	0.648**	0.550	-1.227*	1.435	-1.775**	1.104	0.626
Constant	12.78***	12.44***	7.714*	9.574	7.417	0.0853	-2.284	9.497*
Lags	yes	yes	yes	yes	yes	yes	yes	yes
Observations	285	285	285	285	286	286	286	286
R-squared	0.357	0.487	0.365	0.431	0.233	0.538	0.241	0.362

is because following an increase in trigger requirement, its negative impact on lending is partially offset by the positive effect of a lower capital buffer. In the long term, a 1pp change in capital requirements changes lending growth by 5pp.

Large and small banks tend to react differently to an increase in capital requirements. Large banks seem insensitive to an increase in capital requirements; for these banks capital ratio and lending growth is unaffected. On the other hand, small banks cut lending growth quite sharply as a response. From a policy perspective, this may affect the extent to which total lending to the real economy is affected given a change in capital requirements. This could be due to various factors, but better access to capital markets for large banks may allow large banks to operate with smaller capital buffers.

We have also examined the extent to which financial institutions change the composition of their assets following a change in trigger capital. We found preliminary evidence that small banks react to changes in capital requirements by cutting lending to PNFCs and reduce the riskiness of their balance sheet.

Overall, an increase in capital requirements seem to have a dual effect on lending behaviour; not only it affects the volume of lending, but also the composition and the riskiness of (small) banks' balance sheet.

Appendix

6.A. Appendix

6.A.1. Capital and capital requirements for small and large banks

Figure 6.A.1 shows total capital ratios and capital requirements for large and small banks that are used in our main regressions. There are three main points to make: 1) Small banks operated on average with higher capital buffers than large banks; 2) Small banks' capital ratios seem more sensitive to changes in capital requirements, e.g. during the crisis period; 3) Large banks' capital ratios increased sharply during the crisis, which is consistent with our hypothesis that it is easier for large banks to issue capital when needed (in this case probably to meet an increase market capital requirements).

6.A.2. Long run coefficients - capital ratio regression

Long run coefficients are defined as the sum of the lagged coefficients divided by one minus the sum of the lagged lending coefficients and represent the cumulative effect of a change in capital requirements on changes in capital ratio. Table 6.A.1 shows the long run coefficients for capital requirements estimates using different specifications - POLS with only bank specific variables, POLS with bank-specific and macroeconomic variables, FE and FE for small and large banks.

Figure 6.A.1. Capital ratio and capital requirements for large and small banks

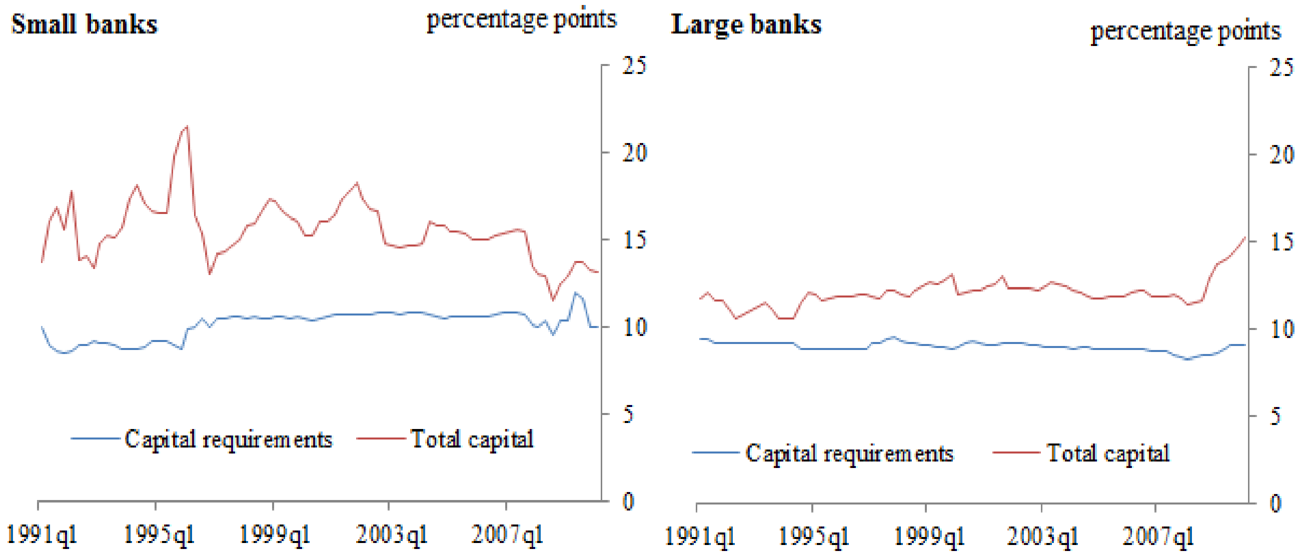


Table 6.A.1. Capital regression, long run coefficients for capital requirements

	Coef.	Std. Err.	t	[95% Conf.	Interval]
POLS	1.240043	0.298847	4.15	0.653674	1.826412
POLS and macro	1.297229	0.313622	4.14	0.681853	1.912606
FE	0.86802	0.24637	3.52	0.384582	1.351458
Small	0.969167	0.292496	3.31	0.395001	1.543334
Large	-0.01264	0.426482	-0.03	-0.853	0.827734

Table 6.A.2 shows the long run coefficients (using FE) for macroeconomic variables, GDP growth and Bank of England base rate, included in our preferred capital specification.

Table 6.A.2. Capital regression - long run coefficients of macroeconomic variables

	Coef.	Std. Err.	t	[95% Conf.	Interval]
GDP growth	0.058092	0.171888	0.34	-0.27918	0.395363
Bank of England rate	-0.02715	0.036047	-0.75	-0.09788	0.043577

6.A.3. Granger causality tests - capital ratio regression

We may have reverse causality problems in the capital regression such that changes in capital affect changes in capital requirements. For example, this may happen if the regulator increases capital requirements following declines in total capital. To understand whether there may be reverse causality problems we have estimated a system of equations with capital and capital requirements as endogenous variables and then tested for joint significance of capital and capital requirements regressors in the capital requirements regression and capital regression respectively. Table 6.A.3 shows that we can reject the hypothesis (at a 10% confidence level) that the capital requirements are jointly zero in the capital equation while we do not reject the hypothesis that the capital variables are jointly zero in the capital requirements regression.

Table 6.A.3. Granger causality tests - capital equation

H0	F	Prob>F
Capital lags jointly zero in capital requirements equation	1.55	0.1852
Capital requirements jointly zero in capital equation	2.35	0.0529

6.A.4. Long run coefficients - lending regressions

Table 6.A.4, first three rows, shows the long run coefficients for capital requirements in the lending regression using different estimation methods. The last three rows of table 6.A.4 show the FE estimates of the long run coefficients for the sectoral lending equations.

Table 6.A.4. Lending regression - long run coefficients of capital requirements

	Coef.	Std. Err.	t	[95% Conf.	Interval]
POLS	-5.79034	2.87037	-2.02	-11.4237	-0.15693
POLS and macro	-5.56517	2.959253	-1.88	-11.3731	0.242785
FE	-5.09619	2.385325	-2.14	-9.77795	-0.41443
Secured	0.277114	2.614225	0.11	-4.8557	5.40993
Unsecured	-6.99696	3.040517	-2.3	-12.9647	-1.02918
PNFC	5.017999	3.13006	1.6	-1.12647	11.16246

Table 6.A.5, first three rows, shows the long run coefficients for the capital buffer in the lending regression using various estimation methods. In the last three rows of Table 6.A.5 we present the estimates of the sectoral lending equations.

Table 6.A.5. Lending regression - long run coefficients of capital buffer

	Coef.	Std. Err.	t	[95% Conf.	Interval]
POLS	-0.951	0.811756	-1.17	-2.54415	0.642161
POLS and macro	-0.86301	0.815094	-1.06	-2.46274	0.736732
FE	-0.493	0.645109	-0.76	-1.75918	0.773173
Secured	1.624404	0.729974	2.23	0.19116	3.057648
Unsecured	-0.18059	0.764588	-0.24	-1.68128	1.32011
PNFC	-0.33319	0.758499	-0.44	-1.82216	1.155786

6.A.5. Effect of capital requirements with low capital buffers

In Column d, Table 6.A.6 we include the results for a regression with an interaction variable between capital requirements and low capital buffers (i.e. 2.4pp, the bottom

25th percentile of the distribution). By interacting capital requirements and small capital buffers, we would like to test whether banks that have a smaller capital buffer react more to a change in capital requirements as they get close to regulatory intervention.

Table 6.A.7 shows that the long run coefficient for the capital requirement remains broadly unchanged compared to our favourite regression but the interaction with low capital buffer is positive and not statistically significant. This suggests that banks with a lower buffer may not react more to a change in capital requirements.

6.A.6. Lending regression in levels

In Table 6.A.8 we have re specified the lending regression with capital requirements and capital buffers in levels to test whether there is a relationship between capital requirements, capital buffers and long run lending growth (not to be confused with long run estimates).

In Table 6.A.9 we have tested whether the coefficients of the lending regression in levels are equal to minus the following lag. If we cannot reject this hypothesis then our equation should be specified in changes rather than levels. We present here the test results for capital requirements and capital buffers. Table 6.A.9 shows that for the majority of the lags the preferred specification is in changes, i.e. there is no long run relationship between capital requirements, buffers and bank lending growth.

Table 6.A.6. Comparing lending regression estimates with banks with low capital buffers

VARIABLES	(a) Lend.g.	(b) Lend.g. (large)	(c) Lend.g. (small)	(d) Lend.g.(low buf.)
Lending growth (-1)	-0.0350	0.0872	-0.0427	-0.0448
Lending growth (-2)	0.0958***	-0.00323	0.101**	0.0786**
Lending growth (-3)	-0.00848	0.0338	-0.0155	0.00680
Lending growth (-4)	0.0172	0.0567	0.0161	-0.000415
ΔCap. req.	-5.200***	-0.455	-5.928***	-4.068**
ΔCap. req. * lar	4.190			
ΔCap. req. (-1)	1.060	0.814	1.789	0.505
ΔCap. req. (-2)	1.664	-0.580	1.339	2.030
ΔCap. req. (-3)	-3.655**	-0.336	-3.713*	-4.873***
ΔCap. req. (-4)	0.814	0.135	0.959	0.819
ΔCap. req. * lar (-1)	0.814			
ΔCap. req. * lar (-2)	-2.332			
ΔCap. req. * lar (-3)	2.953			
ΔCap. req. * lar (-4)	-1.686			
ΔCap. buf.	-0.936**	-0.239	-0.960**	
ΔCap. buf. * lar	0.479			
ΔCap. buf. (-1)	-0.0217	0.210	-0.0598	
ΔCap. buf. (-2)	0.0417	-0.346	0.150	
ΔCap. buf. (-3)	-0.279	0.0845	-0.295	
ΔCap. buf. (-4)	0.699***	-0.0730	0.712***	
ΔCap. buf. * lar (-1)	0.291			
ΔCap. buf. * lar (-2)	-0.413			
ΔCap. buf. * lar (-3)	0.290			
ΔCap. buf. * lar (-4)	-0.955			
ΔCap. req. * lowbuf				0.701
ΔCap. req. * lowbuf (-1)				2.936
ΔCap. req. * lowbuf (-2)				-0.149
ΔCap. req. * lowbuf (-3)				4.112
ΔCap. req. * lowbuf (-4)				-2.566
Bank controls	yes	yes	yes	yes
Macro controls	yes	yes	yes	yes
Constant	-2.666	8.584	-3.510	-8.086
Observations	919	330	589	951
R-squared	0.092	0.101	0.110	0.063
Number of banks	39	10	29	39

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

Table 6.A.7. Low buffer regression - long run coefficients for capital requirements

	Coef.	Std. Err.	t	[95% Conf.	Interval]
ΔCap. req.	-5.821065	2.540115	-2.29	-10.7996	-.8425318
ΔCap. req.*low buffer	5.245531	5.606766	0.94	-5.743528	16.23459

6.A.7. Lagrange multiplier test for RE

Table 6.A.10 shows the output of a Lagrange multiplier test for RE and suggests that we cannot reject the hypothesis that the individual effects is zero. From this test we infer that RE does not capture well the data generating process.

6.A.8. Chow test for large and small banks

In Table 6.A.11 we present the output of a Chow test for large and small banks regressions to test whether all the coefficients are statistically different. The test suggests that large and small estimates are not statistically different. However, we also reject that the variances of the residuals are the same (test not presented in the Annex), therefore violating one of the assumptions of the Chow test.

6.A.9. Testing for RE vs. FE - Hausman test

In Table 6.A.12 we present the output of the Hausman test to determine whether it is better to estimate the lending regression with RE or FE. The Hausman test rejects the hypothesis that the RE and FE are the same. The FE estimator is therefore consistent under the alternative hypothesis of correlation between the regressors and the bank specific effects.

Table 6.A.8. Lending regression in levels

Lending growth	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Lending growth (-1)	-0.01468	0.034225	-0.43	0.668	-0.08184	0.052492
Lending growth (-2)	0.146582	0.034422	4.26	0	0.079027	0.214137
Lending growth (-3)	0.080989	0.034143	2.37	0.018	0.013981	0.147996
Lending growth (-4)	0.063582	0.034984	1.82	0.069	-0.00508	0.13224
Cap. req.	-5.15532	1.280861	-4.02	0	-7.66906	-2.64159
Cap. req (-1)	7.734936	2.533497	3.05	0.002	2.762852	12.70702
Cap. req (-2)	-2.00361	2.806381	-0.71	0.475	-7.51124	3.504018
Cap. req (-3)	-2.97799	2.43492	-1.22	0.222	-7.75661	1.800629
Cap. req (-4)	2.169799	1.307741	1.66	0.097	-0.39669	4.736291
Cap. buf.	-1.37764	0.361523	-3.81	0	-2.08714	-0.66814
Cap. buf. (-1)	1.585172	0.6756	2.35	0.019	0.259282	2.911061
Cap. buf. (-2)	-0.62255	0.758801	-0.82	0.412	-2.11173	0.866621
Cap. buf. (-3)	0.452208	0.668047	0.68	0.499	-0.85886	1.763275
Cap. buf. (-4)	-0.21884	0.346806	-0.63	0.528	-0.89946	0.461779
Provision ratio (-4)	-1.04503	0.670949	-1.56	0.12	-2.36179	0.271738
foreign sub.	0.905159	0.556207	1.63	0.104	-0.18642	1.996737
Non bank	0.728828	1.0269	0.71	0.478	-1.2865	2.744157
Crisis	1.5086	1.203581	1.25	0.21	-0.85347	3.870673
Bank size	-0.35671	0.178548	-2	0.046	-0.70712	-0.00631
Unemployment	-0.13701	0.186071	-0.74	0.462	-0.50218	0.228163
Equity returns	0.053213	0.02993	1.78	0.076	-0.00553	0.111951
GDP growth	0.76824	0.611808	1.26	0.21	-0.43246	1.968935
GDP growth (-1)	-0.67113	0.672803	-1	0.319	-1.99153	0.649275
GDP growth (-2)	0.974283	0.691591	1.41	0.159	-0.38299	2.331556
GDP growth (-3)	-0.67609	0.620931	-1.09	0.277	-1.89469	0.542506
GDP growth (-4)	0.36001	0.568011	0.63	0.526	-0.75473	1.474752
BoE rate	-1.03964	0.658063	-1.58	0.114	-2.33111	0.251834
BoE rate (-1)	0.949283	1.20023	0.79	0.429	-1.40621	3.304779
BoE rate (-2)	1.111292	1.297616	0.86	0.392	-1.43533	3.657912
BoE rate (-3)	-1.65582	1.187231	-1.39	0.163	-3.9858	0.67417
BoE rate (-4)	0.506596	0.641247	0.79	0.43	-0.75188	1.765066
Constant	9.098369	5.237882	1.74	0.083	-1.18117	19.37791

Table 6.A.9. Tests on level regression

		F	Prob>F
Trigger	L0=-L1	2.33	0.1271
	L1=-L2	9.74	0.0019
	L2=-L3	6.86	0.009
	L3=-L4	0.27	0.6017
Buffer	L0=-L1	0.24	0.6272
	L1=-L2	5.23	0.0224
	L2=-L3	0.18	0.6747
	L3=-L4	0.32	0.5708

Table 6.A.10. Lagrangian multiplier test for random effects

	chi2 (1)	Prob>chi2
Var(u)=0	1.71	0.1909

Table 6.A.11. Chow test for large and small banks

	SSR	No. observations	No. vars
Restricted (pooled)	34201.34	919	31
Unrestricted (small and large banks)	33400.02		
Chow test	0.663252		

6.A.10. One-way vs. two-way FE criteria

Both the AIC and BIC suggest that the one-way FE fits better the data (Table 6.A.13). Moreover, the likelihood ratio test does not reject the null that time effects are zero.

6.A.11. Panel VARX for lending and capital buffer

As discussed in Subsection 6.4.3 we discussed possible endogeneity issues for the capital buffer variable. In Table 6.A.14 we present the estimates of the panel VARX for lending

Table 6.A.12. Hausman test for FE and RE

	(b) FE	(B) RE	(b-B) Diff.	sqrt(diag(V_b-V_B)) S.E.
Lending growth (-1)	-0.03581	0.006367	-0.04218	0.000821
Lending growth (-2)	0.09505	0.154082	-0.05903	0.002493
Lending growth (-3)	-0.00494	0.075495	-0.08044	0.007004
Lending growth (-4)	0.017188	0.053701	-0.03651	0.007501
ΔCap. req.	-4.74102	-4.99201	0.250993	0.289038
ΔCap. req. (-1)	1.43708	2.032645	-0.59557	.
ΔCap. req. (-2)	0.98908	1.112056	-0.12298	.
ΔCap. req. (-3)	-2.81129	-2.8502	0.038914	.
ΔCap. req. (-4)	0.389488	0.744257	-0.35477	.
ΔCap. buf.	-0.87012	-1.12065	0.250534	.
ΔCap. buf. (-1)	0.009789	0.294885	-0.2851	.
ΔCap. buf. (-2)	0.027144	-0.09512	0.122268	0.014273
ΔCap. buf. (-3)	-0.30633	-0.06231	-0.24402	.
ΔCap. buf. (-4)	0.682953	0.370156	0.312797	0.051503
Provision ratio (-4)	-2.78612	-0.87169	-1.91443	0.723218
Crisis	0.678878	1.686942	-1.00806	0.571577
Bank size	0.561461	-0.27349	0.834952	0.893048
Unemployment	-0.0731	-0.12126	0.048164	0.182474
Equity returns	0.075922	0.061617	0.014305	.
GDP growth	0.892748	0.855719	0.037029	.
GDP growth (-1)	-0.88366	-0.93575	0.052092	.
GDP growth (-2)	0.965852	0.984272	-0.01842	.
GDP growth (-3)	-1.02769	-0.677	-0.35069	.
GDP growth (-4)	0.623995	0.550994	0.073001	.
BoE rate	-1.09933	-1.10363	0.0043	.
BoE rate (-1)	1.207815	1.232753	-0.02494	.
BoE rate (-2)	0.964072	0.911387	0.052685	.
BoE rate (-3)	-1.8199	-1.5598	-0.2601	.
BoE rate (-4)	0.651187	0.468362	0.182825	.
chi2 (29) = 298.76	Prob>chi2 =	0.0000		

and capital buffer and Table 6.A.15 shows the correlation matrix of the residuals for the panel VARX.

Table 6.A.13. Information criteria for one and two-way FE

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
FE	919	-2958.18	-2915.79	30	5891.589	6036.287
Two-way FE	919	-2958.18	-2881.09	95	5952.187	6410.4

name	command	depvar	npar	title
FE	xtreg	Lending growth	32	
Two-way FE	xtreg	Lending growth	111	

Table 6.A.16 present the results of the Granger causality test which shows that a joint test of significance marginally rejects the hypothesis that lending growth Granger causes changes in capital buffer.

6.A.12. Mean Group estimator for large and small banks

In Table 6.A.17 we show the mean group estimator estimates (Pesaran and Smith (1995)) for large and small banks. As discussed in Subsection 6.4.4, the standard errors are large (not presented here) because of the highly unbalanced nature of the dataset making this estimation technique not applicable to our data.

Table 6.A.14. Panel VAR for lending and capital buffer (OLS)

VARIABLES	(1) Lend. growth	(2) ΔCap. buf.
Lending growth (-1)	0.00650	-0.000120
Lending growth (-2)	0.154***	0.000298
Lending growth (-3)	0.0725**	0.00264
Lending growth (-4)	0.0436	0.00902***
ΔCap. buf. (-1)	-0.354	0.579***
ΔCap. buf. (-2)	0.434	-0.473***
ΔCap. buf. (-3)	-0.239	0.158***
ΔCap. buf. (-4)	0.431**	-0.0539***
ΔCap. req.	-4.027***	-0.862***
ΔCap. req. (-1)	1.269	0.682***
ΔCap. req. (-2)	1.512	-0.356**
ΔCap. req. (-3)	-3.033**	0.163
ΔCap. req. (-4)	0.428	0.282**
Provision ratio (-4)	-1.018	0.131**
Crisis	1.611	0.0682
Bank size	-0.287**	0.0123
Unemployment	-0.115	-0.00537
Equity returns	0.0603*	0.00115
GDP growth	0.768	0.0781
GDP growth (-1)	-0.997	0.0545
GDP growth (-2)	1.173	-0.168**
GDP growth (-3)	-0.727	0.0445
GDP growth (-4)	0.514	0.0330
BoE rate	-1.068	-0.0319
BoE rate (-1)	1.182	0.0450
BoE rate (-2)	1.034	-0.109
BoE rate (-3)	-1.670	0.0987
BoE rate (-4)	0.483	-0.0133
Foreign sub.	0.536	-0.0472
Non bank	0.868	-0.101
Constant	5.028**	-0.147
Observations	919	919
R-squared	0.094	0.362

Standard errors in parentheses
** p<0.01, ** p<0.05, * p<0.1

Table 6.A.15. Correlation matrix of residuals

correlation matrix of residuals		
	Lending growth	ΔCap. buf.
Lending growth	1	
ΔCap. buf.	-0.1026	1

Table 6.A.16. Granger causality test

	F	Prob>F
Lending lags all zero in buffer equation	2.35	0.0528
Buffer lags all zero in lending equation	1.86	0.1150

Table 6.A.17. Mean group estimator

	Large banks	Small banks
Lending growth (-1)	-0.23577	0.024402
Lending growth (-2)	-0.17521	-0.08318
Lending growth (-3)	-0.1405	-0.14597
Lending growth (-4)	-0.05785	0.132386
ΔCap. req.	-4.2294	-3.74219
ΔCap. req. (-1)	-2.77113	-27.4012
ΔCap. req. (-2)	-2.35333	36.73487
ΔCap. req. (-3)	2.932964	-18.3032
ΔCap. req. (-4)	1.495341	-7.15772
ΔCap. buf.	0.741128	-0.19325
ΔCap. buf. (-1)	1.072797	-2.21783
ΔCap. buf. (-2)	0.454269	-2.88997
ΔCap. buf. (-3)	0.883326	-2.7201
ΔCap. buf. (-4)	-0.01803	1.012093
Provision ratio (-4)	-2.14078	1.266076
Crisis	1.564807	-0.31208
Bank size	10.04597	9.101392
Unemployment	0.635783	-0.20617
Equity returns	0.040829	0.288589
GDP growth	-0.73919	-5.90662
GDP growth (-1)	-1.54024	-7.27562
GDP growth (-2)	0.38604	1.499031
GDP growth (-3)	-0.92068	0.07
GDP growth (-4)	-0.45913	-0.09421
BoE rate	0.455695	-0.73178
BoE rate (-1)	0.668943	3.709168
BoE rate (-2)	-0.01136	0.077921
BoE rate (-3)	-0.55963	-11.8986
BoE rate (-4)	0.206908	9.326436
Constant	-123.484	-73.6181

CHAPTER 7

Conclusions

Weak bank lending has plagued the UK economy since the beginning of the financial crisis by lowering economic growth and by affecting the stability of the financial system. Policymakers in countries hit by the financial crisis acted swiftly in an attempt to support bank lending growth.

In the UK, the central bank purchased gilts from non-bank financial institutions funded by the creation of central bank money, the so called Quantitative Easing (QE). Moreover, the government established a macroprudential regulator, the Financial Policy Committee within the Bank of England, to monitor and reduce systemic risk so that excessive credit growth will be less likely in the future. This thesis provides an empirical analysis on the effects of QE and macroprudential policy (focusing on capital requirements) on bank lending using a non-publicly available panel dataset on UK banks.

We find that both QE and capital requirements have a positive effect on bank lending growth even though with different magnitudes. While changes in capital requirements seem to have a economically significant impact on bank lending, QE seems to have a limited impact on lending growth.

Our results also suggest that, in responding to policy actions, there is a certain degree of heterogeneity within the banking system with small banks being the most affected. While this may be a positive development as it may reduce the gap between large and small banks in the lending market (for example because of the effects of QE on bank lending), it provides important challenges to policymakers as large part of lending in the UK is extended by major banks.

In particular, if QE is ineffective in supporting lending growth of large banks, it is unlikely that lending as whole will increase, if anything. In this case, more measures may be necessary for a more significant impact on bank lending. One possible measure would be to increase the amount of asset purchases so that the overall effect on bank lending may become economically significant. An alternative could be to increase the capitalisation of the banking system which might boost the effectiveness of the QE programme, as suggested by our results.

From a macroprudential perspective, if increases in capital requirements are ineffective in changing bank lending behaviour of large banks, it may be difficult for macroprudential regulators to avoid a bank lending boom and the build up of systemic risk. In order to increase the effectiveness of a regulatory shock on large banks it would be useful to investigate the structural reasons for this heterogeneous response. A possible reason may be that large banks, given their systemic importance, incur in low regulatory costs when approaching or breaching capital requirements. If this is a plausible explanation, structural reforms to reduce systemic importance of major institutions may increase the potency of macroprudential tools.

There are several limitations in the analysis on the effects of these policies on the banking system. When we analyse the effects of QE on bank lending we assume that QE affects banks' balance sheets only through deposits, but there may be other channels through which QE affects banks' balance sheets. For example, as long as QE affects yields at the long end of the gilt curve it may also change the steepness of the curve and therefore the capacity of banks to generate profits (recall that banks borrow short and lend long). Moreover, as QE boosts nominal demand, it may affect the structure of banks' balance sheets (e.g. by increasing demand for bank lending) that is not captured by changes in deposits. A more comprehensive empirical analysis of these channels is likely to provide us with a better answer on how QE affect banks' balance sheets and in particular bank lending.

From an econometric perspective, there are two main limitations. First, we use historical information on the relationship between deposits and bank lending before the financial crisis to estimate the impact of changes in deposits during the crisis, i.e. we perform a counterfactual exercise. But the robustness of these estimates rests on the hypothesis that the relationship between changes in deposits and bank lending did not change structurally, which is difficult to test with few observations during the financial crisis period. Performing tests for structural stability with more observations will shed more light on this issue.

Second, the amount of deposits over asset ratio, which we use as a proxy for the effects of QE, may be affected by endogeneity problems. If financial institutions raise deposits because they expect more lending opportunities in the future, our estimated relationship between deposits and lending may represent a correlation between these two quantities rather than a causal relationship. We have tried to exclude this hypothesis by showing that macroeconomic variables (which we use as a proxy for lending opportunities) do not affect the deposit over asset ratio. However, finding an instrument that is correlated with the deposit over asset ratio but uncorrelated with bank lending and estimating the deposit-bank lending relationship with instrumental variable estimator may give us less biased estimates. We leave this work to future research.

The limitations in the analysis on the effects of capital requirements on bank lending are mainly related to the fact that the UK regulator have set capital requirements from a *micro*prudential perspective, i.e. capital requirements are set to preserve the solvency of individual banks rather than the banking system as a whole. Even though it is difficult to overcome this limitation as the macroprudential regulator has been established only recently, this limitation may affect the confidence with which we can use these estimates for policy purposes. For example, the macroprudential regulator may increase capital requirements for all banks to avoid a credit boom and this may have a very different effect on bank lending from an increase in capital requirements for an individual bank due to bank specific (microprudential) problems. Future research may try to tackle this issue by estimating the impact of changes in capital requirements that were common to several banks, e.g. because market risk increased for these banks at the same time. But a better answer will come with more data when the macroprudential regulator will change capital requirements based on systemic risk considerations.

The final limitation is related to the possible endogeneity of changes in capital requirements. As discussed in Chapter 6, a large shock to capital may induce the regulator to increase capital requirements as the bank's default probability increases generating reverse causality problems. However, as described earlier on, capital requirements are set every 18 to 36 months and do not necessarily change promptly in response to changes in banks' capital ratios. Therefore, the institutional setting of capital requirements reduces the extent to which endogeneity problems affect our regressions. Moreover, Granger causality tests suggest that changes in capital requirements Granger cause changes in capital ratios and *not* vice versa. Finding a suitable instrument for changes in capital requirements is a difficult task but possible candidates could be regulatory changes that affect capital requirements but are not related to bank lending. A possible instrument can be found in the way the UK regulator set capital requirements. For example, the UK regulator may increase capital requirements for a new subsidiary that is added to the existing group (FSA (2001)). This shock is unrelated to the lending market of the newly added subsidiary or to its capital position and could therefore be a valid instrument. For several reasons we opted for the use of bank consolidated data in our analysis so we were not able to test this hypothesis. We therefore leave this important question to future research.

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